DOE-2 Modeling Tips
Through 12/31/99

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Calculation of Surface Temperatures in DOE-2

by
Markus Koschenz

Introduction

The present version of *DOE-2.1E* does not calculate the inside surface temperatures because of the weighting factor approach [1]. But the wall and window surface temperatures are important to estimate the radiant temperature as one of the key elements in a thermal comfort evaluation. Therefore, in the frame of the Swiss national project NEFF 640, a model which calculates the surface temperatures has been developed and the required FORTRAN routines have been written. The work was partly performed at the Lawrence Berkeley National Laboratory in cooperation with the Simulation Research Group.

Model

The model is based on an energy balance on the wall surface. The different heat fluxes are shown in Fig. 1. The program *DOE-2.1E* does not take the radiative heat exchange between the room surfaces $\dot{q}_w$ separately into account, but as shown in Fig. 2, a combined convective and radiative film coefficient h is taken into consideration.

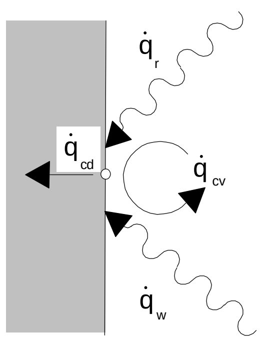


Fig. 1 *Heat fluxes at the wall surface*

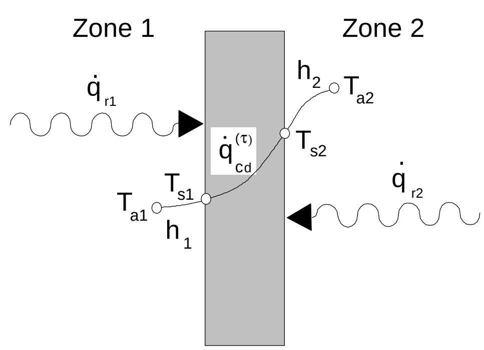


Fig. 2 *Temperature distribution and radiant heat flux for an interior wall (DOE-2.1E model).*

The flux of heat conduction at the wall surfaces is described by the response factors [1] as follows:

$$\dot{q}_{cd1}^{(t)} = \sum_{i=0}^{n} X_i^{'} \cdot T_{s1}^{(t-i\cdot\Delta t)} - \sum_{i=0}^{n} Y_i^{'} \cdot T_{s2}^{(t-i\cdot\Delta t)} + CR \cdot \dot{q}_{cd1}^{(t-\Delta t)} \quad (1)$$

$$\dot{q}_{cd2}^{(t)} = \sum_{i=0}^{n} Y_i^{'} \cdot T_{s1}^{(t-i\cdot\Delta t)} - \sum_{i=0}^{n} Z_i^{'} \cdot T_{s2}^{(t-i\cdot\Delta t)} + CR \cdot \dot{q}_{cd2}^{(t-\Delta t)} \quad (2).$$

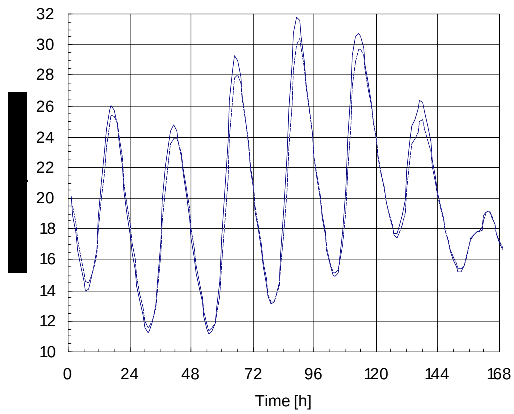
The surface temperatures can be calculated from an energy balance on both sides of the wall:

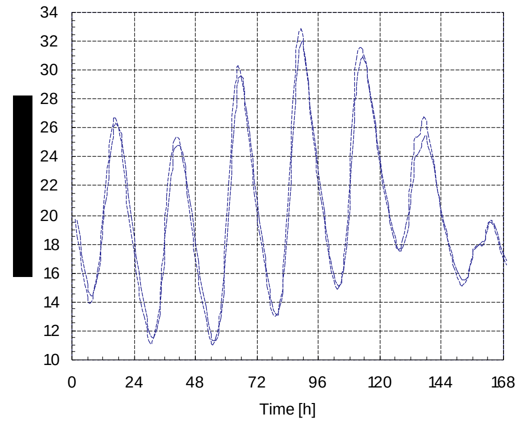
$$\begin{bmatrix} -X_0^{'} - h_1 & Y_0^{'} \\ Y_0^{'} & -Z_0^{'} - h_2 \end{bmatrix} \cdot \begin{pmatrix} T_{s1} \\ T_{s2} \end{pmatrix} = \begin{bmatrix} \sum_{i=1}^{n} X_i^{'} \cdot T_{s1}^{(t-i\cdot\Delta t)} - \sum_{i=1}^{n} Y_i^{'} \cdot T_{s2}^{(t-i\cdot\Delta t)} + CR \cdot \dot{q}_{cd1}^{(t-\Delta t)} - h_1 \cdot T_{a1} - \dot{q}_{r1} \\ -\sum_{i=1}^{n} Y_i^{'} \cdot T_{s1}^{(t-i\cdot\Delta t)} + \sum_{i=1}^{n} Z_i^{'} \cdot T_{s2}^{(t-i\cdot\Delta t)} - CR \cdot \dot{q}_{cd2}^{(t-\Delta t)} - h_2 \cdot T_{a2} - \dot{q}_{r2} \end{bmatrix} \quad (3).$$

The right side of the system of equations (3) only contains surface temperatures and conduction heat fluxes from previous time steps. The zone air temperature and the radiative heat flux to the wall for the current time step are output data of the present *DOE-2* program and therefore also known.

Comparison with measurements

The model has been compared with the measured data sets used in the validation efforts within IEA-ECB Annex 21 [2] and with measurements from the Pala test case [3].





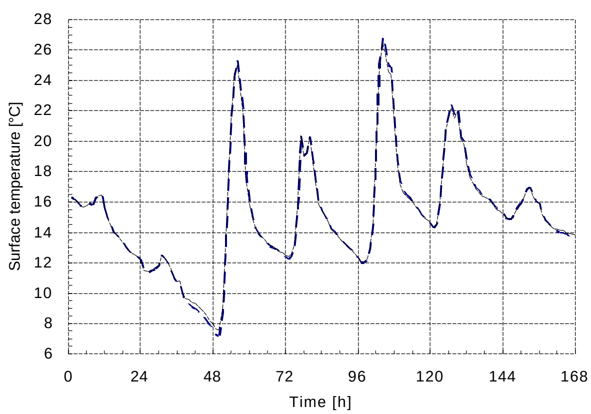
___ DOE-2.1E Simulation
- - - IEA Measurements

Fig. 3 *Inside surface temperature of the ceiling.*

Fig 4. *Inside surface temperature of the exterior wall.*

Fig. 3 and 4 show the good agreement between the measurements and the simulation.

Additional comparisons have been made with a window model developed for the Building Simulation Program *TRNSYS* [4]. The calculated window surface temperature for a Window type 4651 has been compared with the result of the new surface temperature routine in *DOE-2.1E*. The comparison shows an excellent agreement (Fig. 5).



___ DOE-2.1E Simulation -- TRNSYS Type 97 with DOE 2.1 E Window model

Fig. 5 *Window inside surface temperature.*

Additional Keywords

BUILDING-LOCATION

SURF-TEMP-CALC — Defines whether the surface temperature is performed or not. The allowable code-words are YES and NO (the default).

WALL LEVEL KEYWORD

The surface temperature calculation is performed for EXTERIOR-WALL, WINDOW, DOOR, UNDERGROUND-WALL, INTERIOR-WALL and INTERIOR-WINDOW but not for the wall type INTERNAL and AIR.

INSIDE-SURF-TEMP — Defines whether the specified surface temperature is written to a separate output file or not. The allowable code-words are YES and NO (the default).

The output data are written to the file fort.16 in unix and for016.dat in vax/vms with the following format:

```
       ROOM  S-TR  S-TR        ROOM  WIN-  WIN-        ROOM  S-TR  S-TR  ROOM
       -1    -C45  -C45       -1     1     1           -1    -C02  -C02  -2

521 1  27.3  27.0  20.2  21.7  27.3  22.8 -17.8  21.7  27.3  27.0  21.4  21.0
521 2  26.7  26.4  20.2  21.7  26.7  22.6 -17.8  21.7  26.7  26.4  21.4  21.0

(1)    (2)   (3)   (4)   (5)   (2)   (6)  (7)    (5)   (2)   (3)   (8)   (9)
```

1 Date and Time
2 Zone air temperature
3 Wall inside surface temperature
4 Wall outside surface temperature
5 Outside air temperature
6 Window inside surface temperature
7 Window outside surface temperature (not available in the current version; therefore 0°F or -17.8°C)
8 Wall surface temperature in NEXT-TO zone
9 Air temperature in NEXT-TO zone

The new routine calculates the mean radiative temperature for every zone as a sum of the area weighted surface temperatures and makes it available as an additional system hourly report variable. Also the operative temperature which is defined as a combination of the zone air temperature and the mean radiative temperature is calculated and available as an hourly report variable.

Hourly-Report Variable List SYSTEM

VARIABLE-TYPE = u-name of ZONE

Variable-List Number	Variable in FORTRAN Code	Description
91	TMR	Mean radiative temperature
92	TEFF	Operative temperature

List of Symbols

CR	Common ratio	$[-]$
h	Combined film coefficient (convective and radiative)	$[W/(m^2K)]$
$\dot{q}_{cd}^{(t)}$	Wall conduction	$[W/m^2]$
$\dot{q}_{cv}$	Convective heat flux	$[W/m^2]$
$\dot{q}_r$	Radiative heat flux from people, equipment and solar radiation	$[W/m^2]$
$\dot{q}_w$	Radiative heat flux from other surfaces	$[W/m^2]$
T_a	Air temperature	$[K]$
T_s	Surface temperature	$[K]$
t	Time	$[h]$
Δt	Time step	$[h]$
X', Y', Z'	Surface to surface response factors	$[W/(m^2K)]$

References

[1] *DOE-2 Engineers Manual Version 2.1 A, LBNL University of California Berkeley, Nov 1982.*

[2] *Empirical Validation Data Sets 099 and 110 from EMC Test Room, BRE (Building Research Establishment), IEA Annex 21, March 1992*

[3] *R. Meldem and F. Winkelmann, Comparison of DOE-2 with Measurements in the Pala Test Houses, California Institute for Energy Efficiency report, July 1995*

[4] *R. Weber und M. Koschenz, Description of Type 97 for TRNSYS, Model for the Calculation of Multi Layer Windows, EMPA Abteilung Haustechnik, Dez. 1995*

From the Building Energy Simulation User News, Vol. 19, No. 4 (Winter 1998)

Using DOE-2 to Estimate Component Heating and Cooling Loads of the Entire U.S. Building Stock

by
Joe Huang

A recently completed project for the U.S. Department of Energy's (DOE) Office of Building Equipment combined DOE-2 results for a large set of prototypical commercial and residential buildings with data from the Energy Information Administration's (EIA) building energy surveys to estimate the total heating and cooling loads in U.S. buildings attributable to various building components such as windows, roofs, walls, etc. This information is useful for gauging the national conservation potentials for DOE's research in building energy efficiency.

The prototypical building descriptions and DOE-2 input files were developed from 1985 to 1992 to provide benchmark hourly building loads for the Gas Research Institute (GRI) and include 112 single-family, 66 multi-family, and 481 commercial building prototypes (Tables 1 and 2). The methodology used to develop these prototypes is described in three technical reports listed at the end of this summary that are available from GRI or LBNL. The DOE-2 input files for the commercial buildings have been put on the Simulation Research Group's ftp site at http://ftp.gundog.lbl.gov. The input files for the residential prototypes will be put on the web after they have been converted from a custom pre-processor procedure to standard DOE-2.1E macro language. Due to their size, the output hourly end-use loads files are on tape storage, but arrangements can be made to access them through ftp. Those interested should contact the author for information (YJHuang@lbl.gov).

Table 1. Prototypical Residential Buildings

Single-family Vintages		**Locations**		
A (pre-1940's)	A1 (retrofitted pre-1940's)	Boston	New York	Chicago
B (1950-1970's)	B1 (retrofitted 1950-1970's)	Minneapolis	Washington	Atlanta
C (1980's)		Miami	Fort Worth	Lake Charles
		Denver	Albuquerque	Phoenix Seattle
Multi-family Vintage/Size combinations (varies by region)		San Francisco	Los Angeles	Kansas City
small pre-1940	large pre-1940's			
small 1950-1959s	large 1960-1969s			
small 1960-1969s	large 1970-1979s			
small 1980s	large 1980s			

Table 2. Prototypical Commercial Buildings

Building Types		**Vintages**	
Large Office	Small Office	Old shell, Old system	Old shell, New system
Large Retail	Small Retail	New shell, New system	
Large Hotel	Small Hotel		
Sit-down Restaurant	Fast-foods Restaurant	**Locations**	
Hospital	Secondary School	Minneapolis	Chicago
Supermarket	Warehouse	Washington	Houston
		Los Angeles	

The DOE study consisted of two distinct tasks.

1. The first was to do DOE-2 simulations of the prototypical buildings and develop methods to extract the building loads attributable to different parts of a building. For the commercial buildings, DOE-2 functions were written that corrected the LOADS loads for the actual zone temperature hour-by-hour and apportioned the corrected load to either heating or cooling depending on the building's load history. For the residential buildings, parametric simulations were used in which the heat flows through a building component were eliminated, and the resulting changes in building loads recorded.
2. The second task was to estimate the number of buildings or floor area represented by each *prototypical* building based on EIA's Commercial Building Energy Consumption Survey (CBECS) and Residential Energy Consumption Survey (RECS). These building stock data were then multiplied by the prototypical building component loads to derive aggregated totals by region, vintage, and building type.

This bottoms-up engineering approach produced estimates of 1.33 Quads of heating and 1.63 Quads of cooling energy use for 12 major building types representing three-quarters of the commercial building floor area, and 5.93 Quads of heating and 1.45 Quads of cooling for all U.S. residential buildings. Scaled to the entire commercial building stock, the heating energy use is quite close to EIA, but 40% lower than GRI estimates; the cooling energy use is 10-50% higher than EIA, but 20% lower than GRI estimates. The residential heating and cooling energy uses are both within 10% of EIA but are 20% higher for heating and 20% lower for cooling compared to GRI estimates.

The main objective of the study, however, was not to derive another estimate of national building energy use, but to provide insight into the *composition* of the building loads by type, vintage and building component. Figures 1 and 2 show the national heating and cooling loads for the residential and commercial building stock in the form of pie charts. The size of the heating and cooling pies are proportional to the load. Those building components with net heat losses are shown with stripes, while those with net heat gains are shown by cross-hatched pie slices. The contributing loads are shown on the upper half of each pie, which are partially offset by "free heat" or "free cooling" to the right of each pie. The remaining deficits are the net heating or cooling loads, which are shown as the exploded pie slices to the lower left. The enlarged slices show the heating and cooling energy use needed to meet the loads, which are substantially greater due to the inefficiencies of the system, plant, and electricity generation and transmission.

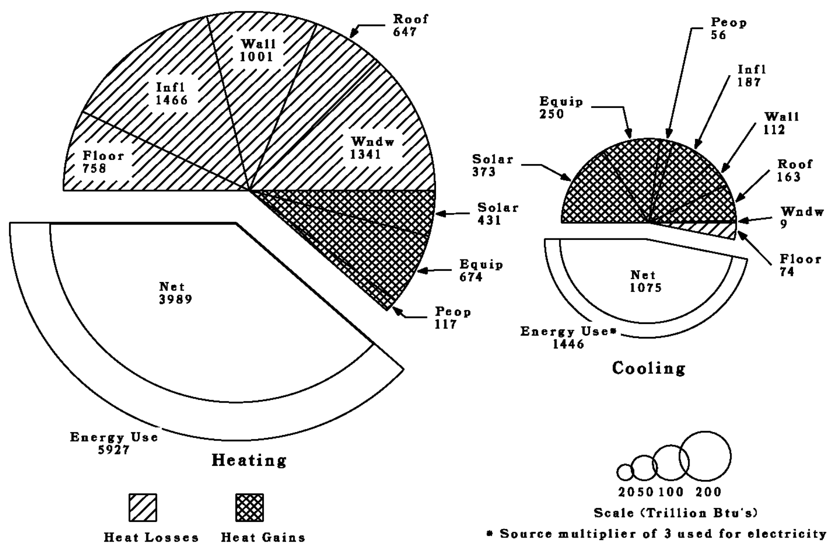


Figure 1: Aggregate Component Loads for all Residential Buildings (Trillion Btus)

Wall = wall heat flow	Solar = window solar heat gain	Infl = infiltration heat flow
Roof = roof heat flow	Floor = ground and floor heat flow	Wndw = window conduction heat flow
Net = net heat flow	Peop = people heat gain	Equip = equipment heat gain, incl. lights

References
Huang, Y.J. and Franconi, E.M., "Commercial Heating and Cooling Loads Component Analysis", LBL-33101, Lawrence Berkeley National Laboratory, Berkeley CA (1998).

Huang, Y.J., Hanford, J.W. and Yang, F.Q., "Residential Heating and Cooling Loads Component Analysis", LBL-37208, Lawrence Berkeley National Laboratory, Berkeley CA (1998). Huang, Y.J., Akbari, H., Rainer, L., and Ritschard, R.L. "481 Prototypical Commercial Buildings for Twenty Urban Market Areas" (Technical documentation of building loads data base developed for the GRI Cogeneration Market Assessment Model), Gas Research Institute Report 90/0326, also LBL Report 29798 (1991).

Ritschard, R.L. and Huang, Y.J. "Multifamily heating and cooling requirements: assumptions, methods, and summary results", Gas Research Institute Report 88/2039 (1988).

Ritschard, R.L. Hanford, J.W. and Sezgen, A.O., "Single-family heating and cooling requirements: assumptions, methods, and summary results", Gas Research Institute Report 91/0236, also LBL- *References*
Huang, Y.J. and Franconi, E.M., "Commercial Heating and Cooling Loads Component Analysis", LBL-33101, Lawrence Berkeley National Laboratory, Berkeley CA (1998).

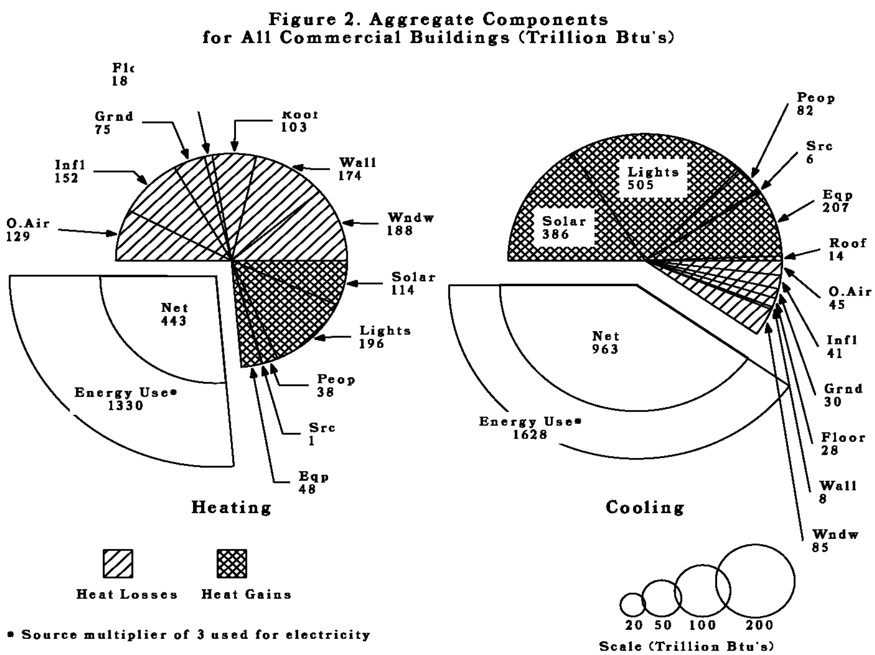


Figure 2: Aggregate Component Loads for all Commercial Buildings (Trillion Btus)

Wall = wall heat flow	Solar = window solar heat gain	Infl = infiltration heat flow
Roof = roof heat flow	Floor = floor heat flow	Wndw = window conduction heat flow
Net = net heat flow	Peop = people heat gain	Equip = equipment heat gain
Floor = floor heat flow	Grnd = ground heat flow	Src = heat gain from non-electrical processes
	O.Air = outside air heat flow	Lights = lighting heat gain

From the Building Energy Simulation User News, Vol. 19, No. 3 (Fall 1998)

How to Simulate a Fuel Cell using DOE-2.1E

by
Fred Buhl

Question:

I'm trying to simulate a fuel cell using the gas turbine model in the DOE-2.1E PLANT subprogram. Basically I want to replace the performance curves with new ones that will make the gas turbine perform like a fuel cell. However, I have run into problems with information contained in the DOE-2.1E Supplement. There is conflicting data about the gas turbine performance curves; p. 4.58 does not agree with p. 4.83.

Answer:

The coefficients for GTURB-I/O-FPLR given on p. 4.58 of the DOE-2.1E *Supplement* are correct. The values on p. 4.83 seem to reflect an older version of DOE-2. I reviewed the description of the gas turbine in the *Supplement* and it seems to be a little confusing. Let me clarify how the model works. The basic equation is

```
GFUEL = CAP*(1.0/GTURB-GEN-EFF)*
        (FUELG(1) + FUELG(2)*PLR + FULEG(3)*PLR*PLR)
```

where:

GFUEL	is the fuel consumed by the gas turbine
CAP	is the capacity, a fixed number not altered by any curve
GTURB-GEN-EFF	is the PLANT-PARAMETERS keyword, the fuel to electric conversion efficiency at full load (default is .19)
FUELG(1), FUELG(2), FUELG(3)	are the coefficients of the EQUIPMENT-QUAD keyword GTURB-I/O-FPLR; the default coefficients are .442979, .3974, .1569621
PLR	is the part load ratio PLR = LOAD/CAP; PLR must be bigger than the minimum operating load ratio RMIN which defaults to .1 (not .3 as indicated on p. 4.57)

The amount of high temperature recoverable heat is set with a similar equation:

```
EEXHG = CAP*(1.0/GTURB-GEN-EFF)*GTURB-EXH-EFF*
        (THMXH(1) + THMXH(2)*PLR + TH MXH(3)*PLR*PLR)
```

where:

EEXHG	is the recoverable heat available for the hour
GTURB-EXH-EFF	is the PLANT-PARAMETERS keyword, the fraction of fuel energy turned into recoverable heat at full load (default .55)
THMXH(1), THMXH(2) THMXH(3)	are the coefficients of the EQUIPMENT-QUAD keyword GTURB-EXH-FPLR; default coefficients. are 0.295626, 0.4930194, 0.2113548

That's it. Note that GTURB-TEX-FPLR does not exist and GTURB-CAP-FT is never used, contrary to what is stated on p. 4.56 of the *Supplement*. To simulate a fuel cell you need to just put in the correct full load efficiency GTURB-GEN-EFF and put in the correct part load performance with your own GTURB-I/O-FPLR.

Note very carefully the form of the equation for GFUEL. GTURB-I/O-FPLR multiplies the capacity, CAP, not the load for the hour. So, if you want a constant efficiency as a function of part load, your GTURB-I/O-FPLR curve should be 0.0 + 1.0*PLR + 0.0*PLR*PLR. That is, your coefficients should be 0.0, 1.0, 0.0. The same is true for all DOE-2 FPLR curves.

From the Building Energy Simulation User News, Vol. 19, No. 1 (Spring 1998)

Underground Surfaces: How to Get a Better Underground Surface Heat Transfer Calculation in DOE-2.1E

by
Fred Winkelmann

Underground surfaces in DOE-2.1E are walls or floors that are in contact with the ground. An example is a slab-on-grade or a basement wall. Underground surfaces are entered using the UNDERGROUND-WALL command, or the equivalent command, UNDERGROUND-FLOOR. Check the description of these commands in the *Reference Manual* for information on the keywords for these surfaces.

Heat Transfer

Care needs to be taken in describing the construction of an underground surface in order to get a correct calculation of the heat transfer through the surface and a correct accounting for the thermal mass of the surface, which is important in the weighting factor calculation for the space. In the LOADS program, DOE-2 calculates the heat transfer through the underground surface as

$$Q = UA(T_g - T_i)$$

where U is the conductance of the surface, A is the surface area, T_g is the ground temperature and T_i is the inside air temperature. *If the raw U-value of the surface is used in this expression the heat transfer will be grossly overcalculated.* This is because the heat transfer occurs mainly through the surface's exposed perimeter region (since this region has relatively short heat flow paths to the outside air) rather than uniformly over the whole area of the surface. For this reason, users are asked to specify an effective U-value with the U-EFFECTIVE keyword. This gives

$$Q = [U\text{-}EFFECTIVE]*A(T_g - T_i)$$

In general U-EFFECTIVE is much less than the raw U-value.

The following procedure shows how to determine U-EFFECTIVE for different foundation configurations. It also shows how to define an effective construction for an underground surface that properly accounts for its thermal mass when custom weighting factors are specified. The procedure assumes that the monthly ground temperature is the average outside air temperature delayed by three months, which is similar to how the ground temperatures on the weather file are calculated. To force the program to use the weather file values, do *not* enter ground temperatures using the GROUND-T keyword in the BUILDING-LOCATION command.

Procedure for defining the underground surface construction

1. Choose a value of the perimeter conduction factor, *F2*, from Table 1, 2 or 3 for the configuration that best matches the type of surface (slab floor, basement wall, crawl-space wall), foundation depth and amount/location of insulation.

2. Using *F2*, calculate R_{eff}, the *effective resistance* of the underground surface, which is defined by the following equation:

   $$R_{eff} = A / (F2*P_{exp})$$

   where A is the area of the surface (ft^2 or m^2) and P_{exp} is the length (ft or m) of the surface's perimeter that is exposed to the outside air. Figures 1 and 2 show values of P_{exp} for example foundation configurations. If P_{exp} is zero**, set R_{eff} to a large value, e.g. R_{eff} = 1000.

** The procedure makes the approximation that the heat transfer through an underground surface with no exposed perimeter, such as a basement floor, is zero.

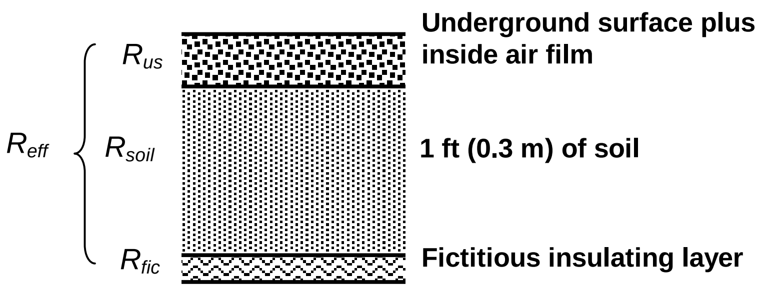
3. Set U-EFFECTIVE = $1/R_{eff}$.

   The program will calculate the heat transfer through the underground surface to be

   $Q = [U\text{-}EFFECTIVE]^* A\,(T_g - T_i)$

4. Define a construction, shown in the figure below, consisting of the following:

   - The underground wall or floor, including carpeting, if present, and inside film resistance (overall resistance = R_{us})
   - A 1-ft (0.3-m) layer of soil (resistance = R_{soil} = 1.0 hr-ft^2-F/Btu [0.18 m^2-K/W])
   - A fictitious insulating layer (resistance = R_{fic})



The layer of a soil represents the thermal mass of the ground in contact with the underground surface (a 1-ft [0.3-m] layer is sufficient to account for most of the thermal mass effect). The fictitious insulating layer is required to give the correct effective resistance for the construction, i.e.

$$R_{eff} = R_{us} + R_{soil} + R_{fic}$$

From this we get

$$R_{fic} = R_{eff} - R_{us} - R_{soil}$$

The procedure for defining this construction is shown in the following example.

Example: 50' x 100' slab-on-grade.
The slab consists of uncarpeted, 4-in (10-cm) heavy-weight concrete (CC03 in the DOE-2.1E library), with resistance = 0.44 hr-ft^2-F/Btu (0.078 m^2-K/W). The foundation depth is 4 ft (1.22 m) with R-10 (1.76 m^2-K/W) exterior insulation, which gives F2 = 0.50 Btu/hr-F-ft (0.86 W/m-K) from Table 1. We then have:

Slab surface area:	A = 50x100 = 5000 ft^2
Slab exposed perimeter:	P_{exp} = (2x50) + (2x100) = 300 ft
Effective slab resistance:	$R_{eff} = A/(F2^*P_{exp})$ = 5000/(0.68*300) = 33.3
Effective slab U-value:	U-EFFECTIVE = $1/R_{eff}$ = 0.030
Actual slab resistance:	R_{us} = 0.44 + R_{film} = 0.44 + 0.77 = 1.21
Resistance of fictitious layer:	$R_{fic} = R_{eff} - R_{us} - R_{soil}$ = 33.3 – 1.21 – 1.0 = 31.1

Here, 0.77 hr-ft^2-F/Btu (0.14 m^2-K/W) is the average of the air film resistance for heat flow up— 0.61 hr-ft^2-F/Btu (0.11 m^2-K/W)—and heat flow down— 0.92 hr-ft^2-F/Btu (0.16 m^2-K/W). For vertical surfaces, such as basement walls, you can use R_{film} = 0.68 hr-ft^2-F/Btu (0.12 m^2-K/W).

The input would look like:

$ Slab-on-grade $

```
MAT-FIC-1  = MATERIAL  RESISTANCE = 31.1  .. $ the Rfic value

SOIL-12IN = MATERIAL  THICKNESS = 1.0  CONDUCTIVITY = 1.0
                      DENSITY = 115  SPECIFIC-HEAT = 0.1 ..

LAY-SLAB-1 = LAYERS  MATERIAL = (MAT-FIC-1,SOIL-12IN,CC03)
                     INSIDE-FILM-RES = 0.77 ..

CON-SLAB-1 = CONSTRUCTION LAYERS = LAY-SLAB-1 ..
  .
  .
SLAB-1 = UNDERGROUND-FLOOR HEIGHT = 50
                           WIDTH = 100
                           TILT = 180
                           U-EFFECTIVE = 0.030
                           CONSTRUCTION = CON-SLAB-1 ..
```

Caution: If you change the dimensions of the slab later, be sure to recalculate R_{fic}. For example, if the 50x100-ft slab is changed to 50x80-ft exposed perimeter becomes 260-ft, and we get R_{eff} = 4000/(0.50*260) = 30.8 (rather than 33.3), U-EFFECTIVE = 1/30.8 = 0.033 (rather than 0.030), and R_{fic} = 30.8 – 1.21 – 1.0 = 28.6 (rather than 31.1).

Note (1):
For basements (Table 2) and crawl spaces (Table 3) an 8-in (20.3-cm) high section between ground level and the top of the underground wall is included in the F2 calculation and so does not have to be entered as a separate exterior wall. However, for shallow basements (Table 2) the wall section between the top of the underground wall and main level of the building should be entered as a separate exterior wall.

Note (2):
The floor of a crawl space (Table 3) should be entered as an UNDERGROUND-FLOOR consisting of a 1-ft (0.3-m) layer of soil with a fictitious insulation layer underneath it. Because the exposed perimeter of the floor in this case is zero, the heat transfer is zero, so the fictitious insulation layer should have a very high resistance and U-EFFECTIVE should be zero. The input would look like:

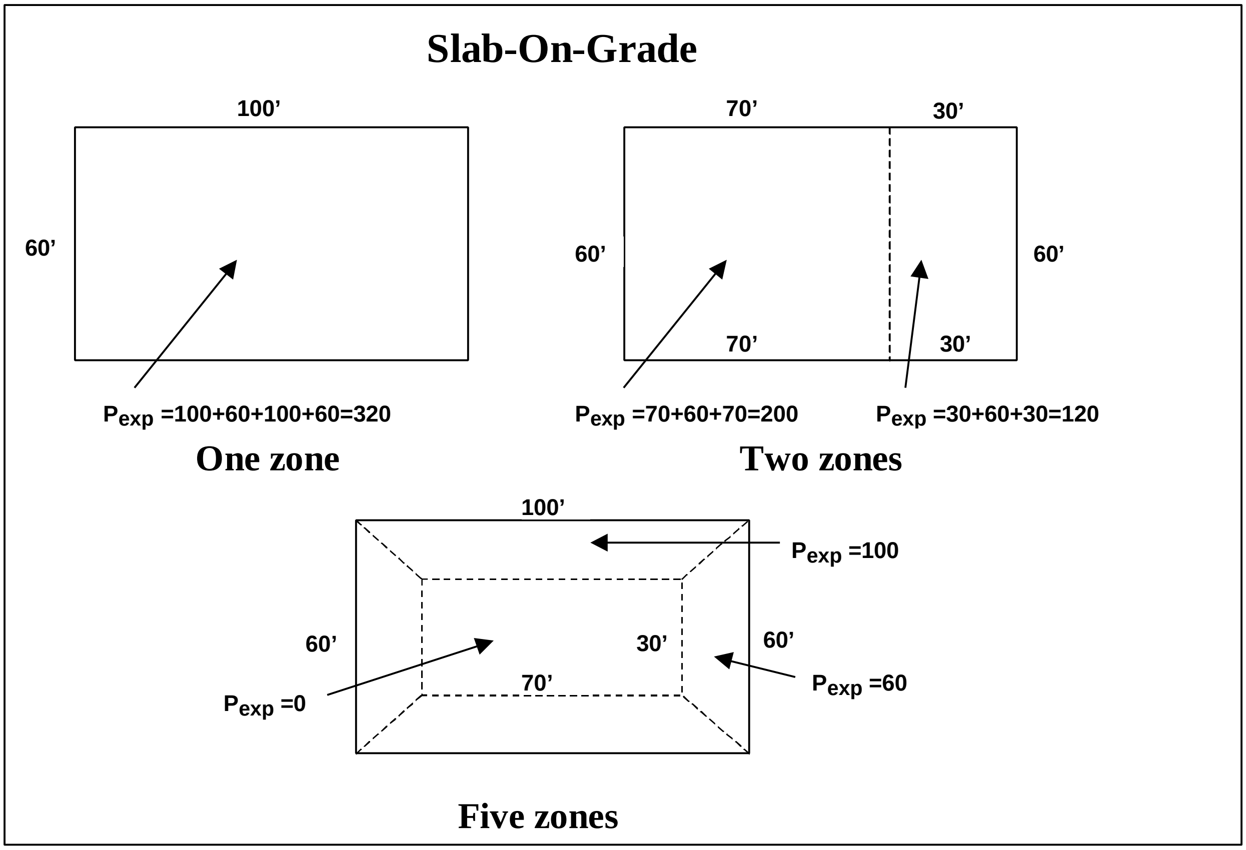
$ Crawl space floor $

```
MAT-FIC-1  = MATERIAL RESISTANCE = 1000  ..

SOIL-12IN = MATERIAL  THICKNESS = 1.0
                      CONDUCTIVITY = 1.0
                      DENSITY = 115
                      SPECIFIC-HEAT = 0.1 ..

LAY-FLOOR-1 = LAYERS  MATERIAL = (MAT-FIC-1, SOIL-12IN)
                      INSIDE-FILM-RES = 0.77 ..

CON-FLOOR-1 = CONSTRUCTION LAYERS = LAY-FLOOR-1 ..
 ....

FLOOR-1 = UNDERGROUND-FLOOR HEIGHT = 50
                            WIDTH = 100
                            TILT = 180
                            U-EFFECTIVE = 0.0
                            CONSTRUCTION = CON-SLAB-1 ..
```

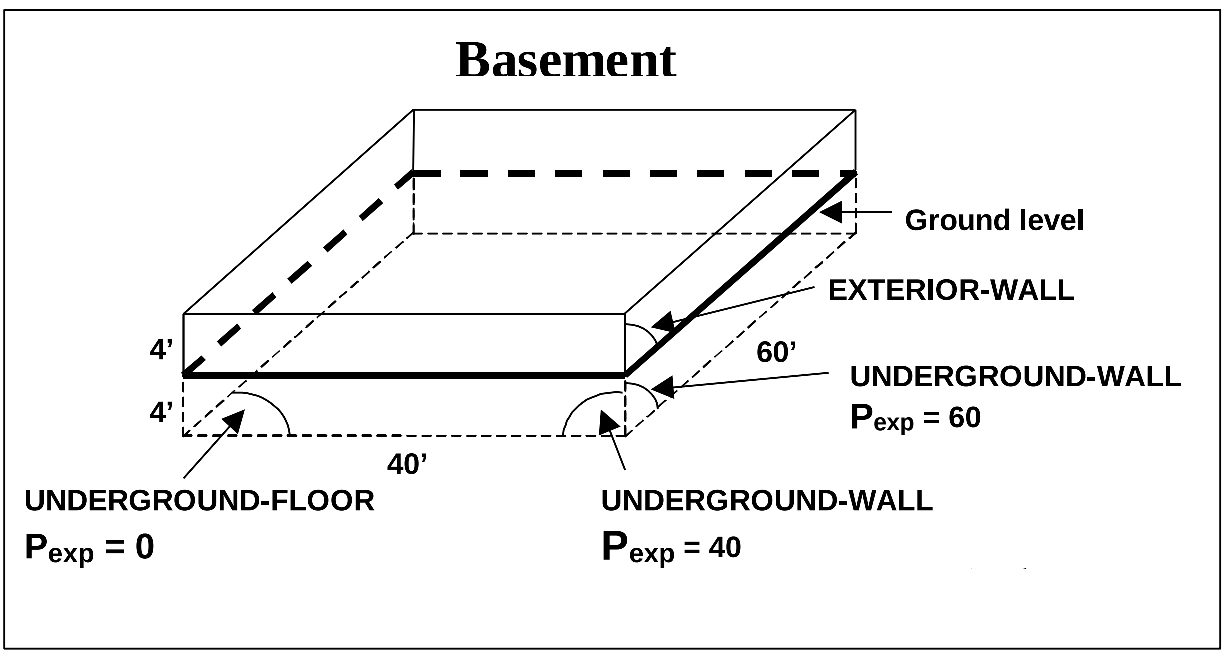
Thermal Mass

Underground surfaces are usually concrete and therefore have high thermal mass. Because of its heat storage capacity this mass attenuates loads due to heat gains (from lights, solar, people, etc.) and causes a time delay between when the heat gain occurs and when it appears as a load on the HVAC system. In general, the higher the heat capacity and the more closely coupled the mass is to the room air, the larger this delay and attenuation will be.

DOE-2 will account for thermal mass only if (1) the underground surface is entered with a layers-type construction, following the procedure described in the previous section; and (2) custom weighting factors are calculated for the space, i.e., FLOOR-WEIGHT = 0 in the SPACE or SPACE-CONDITIONS command.



Exposed perimeter calculation for slab-on-grade examples.



Exposed perimeter calculation for basement.

Table 1: Perimeter Conduction Factors for Concrete Slab-On-Grade*

Slab-On-Grade			
		PERIM-CONDUCT Btu/hr-F-ft (W/m-K)	
Foundation depth	Insulation Configuration (see sketch for location of insulation)	Uncarpetted	Carpetted
2 ft	Uninsulated	1.10 (1.90)	0.77 (1.33)
	R-5 exterior	0.73 (1.26)	0.54 (0.93)
	R-10 exterior	0.65 (1.12)	0.49 (0.85)
	R-5 interior; R-5 gap	0.75 (1.30)	0.57 (0.98)
	R-10 interior	0.89 (1.54)	0.46 (0.79)
	R-10 interior; R-5 gap	0.70 (1.21)	0.53 (0.92)
	R-10 interior; R-10 gap	0.68 (1.17)	0.52 (0.90)
	R-5 2-ft perimeter; R-5 gap	0.78 (1.35)	0.60 (1.04)
	R-10 2-ft perimeter; R-5 gap	0.73 (1.26)	0.57 (0.98)
	R-10 4-ft perimeter	0.79 (1.36)	0.59 (1.02)
	R-10 15-ft perimeter, R-5 gap	0.39 (0.67)	0.34 (0.59)
	R-5 16-in exterior, R-5 2-ft horizontal	0.65 (1.12)	0.48 (0.83)
	R-5 16-in exterior, R-5 4-ft horizontal	0.58 (1.00)	0.43 (0.74)
	R-10 16-in exterior, R-5 2-ft horizontal	0.56 (0.97)	0.41 (0.71)
	R-10 16-in exterior, R-5 4-ft horizontal	0.47 (0.81)	0.35 (0.60)
4 ft	Uninsulated	1.10 (1.90)	0.77 (1.33)
	R-5 exterior	0.61 (1.05)	0.46 (0.79)
	R-10 exterior	0.50 (0.86)	0.37 (0.64)
	R-15 exterior	0.44 (0.76)	0.33 (0.57)
	R-20 exterior	0.40 (0.69)	0.30 (0.52)
	R-5 interior; R-5 gap	0.63 (1.09)	0.48 (0.83)
	R-10 interior; R-5 gap	0.54 (0.93)	0.42 (0.73)
	R-15 interior; R-5 gap	0.50 (0.86)	0.38 (0.66)
	R-20 interior; R-5 gap	0.47 (0.81)	0.36 (0.62)
	R-5 4-ft perimeter; R-5 gap	0.68 (1.17)	0.54 (0.93)
	R-10 4-ft perimeter; R-5 gap	0.61 (1.05)	0.49 (0.85)
	R-10 4-ft perimeter	0.79 (1.36)	0.59 (1.02)
	R-10 15-ft perimeter, R-5 gap	0.39 (0.67)	0.34 (0.59)
	R-5 16-in exterior, R-5 2-ft horizontal	0.65 (1.12)	0.48 (0.83)
	R-5 16-in exterior, R-5 4-ft horizontal	0.58 (1.00)	0.43 (0.74)
	R-10 16-in exterior, R-5 2-ft horizontal	0.56 (0.97)	0.41 (0.71)
	R-10 16-in exterior, R-5 4-ft horizontal	0.47 (0.81)	0.35 (0.60)

*Source: Y.J.Huang, L.S.Shen, J.C.Bull and L.F.Goldberg, "Whole-House Simulation of Foundation Heat Flows Using the DOE-2.1C Program," ASHRAE Trans. 94 (2), 1988, updated by Y.J.Huang, private communication.

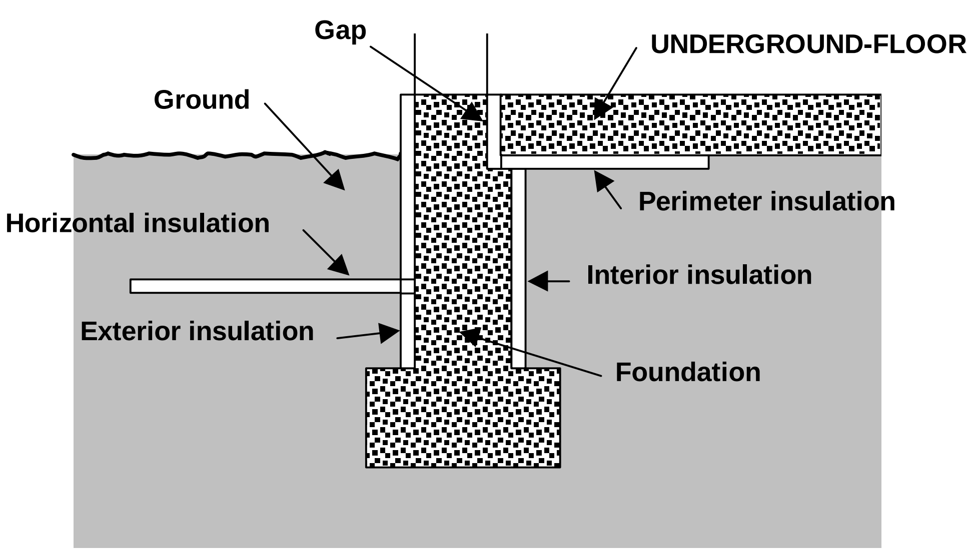
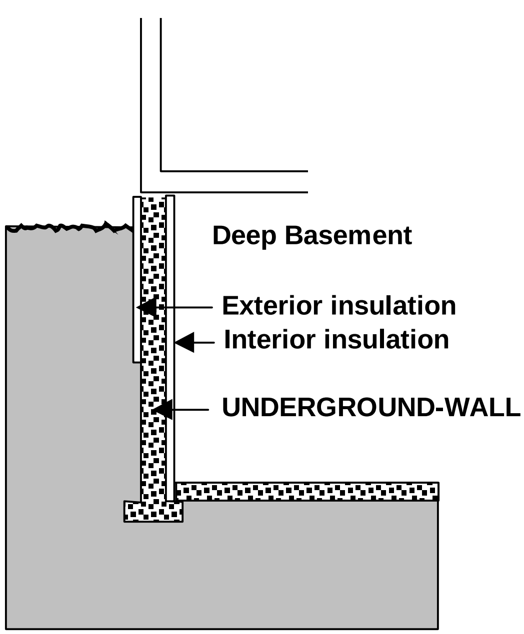


Table 2: Perimeter Conduction Factors for Basement Walls*

Basement Wall		
Underground Wall Height	**Construction (see sketch for location of insulation)**	**PERIM-CONDUCT Btu/hr-F-ft (W/m-K)**
8 ft (deep basement)	R-0 (uninsulated), concrete	1.94 (3.35)
	4-ft R-5 exterior, concrete	1.28 (2.21)
	8-ft R-5 exterior, concrete	0.99 (1.71)
	4-ft R-10 exterior, concrete	1.15 (1.99)
	8-ft R-10 exterior, concrete	0.75 (1.30)
	8-ft R-15 exterior, concrete	0.63 (1.09)
	8-ft R-20 exterior, concrete	0.56(0.97)
	8-ft R-10 interior, concrete	0.78 (1.35)
	R-0, wood frame	1.30 (2.25)
	R-11, wood frame	0.88 (1.52)
	R-19, wood frame	0.79 (1.37)
	R-30, wood frame	0.66 (1.14)
4 ft (shallow basement)	R-0 (uninsulated), concrete	1.61 (2.78)
	R-5 exterior, concrete	0.89 (1.54)
	R-10 exterior, concrete	0.73 (1.26)
	R-15 exterior, concrete	0.66 (1.14)
	R-20 exterior, concrete	0.65 (1.12)
	R-10 interior, concrete	0.79 (1.37)
	R-0, wood frame	1.10 (1.90)
	R-11, wood frame	0.80 (1.38)
	R-19, wood frame	0.74 (1.28)

*Source: Y.J.Huang, L.S.Shen, J.C.Bull and L.F.Goldberg, "Whole-House Simulation of Foundation Heat Flows Using the DOE-2.1C Program," ASHRAE Trans. 94 (2), 1988, updated by Y.J. Huang, private communication.



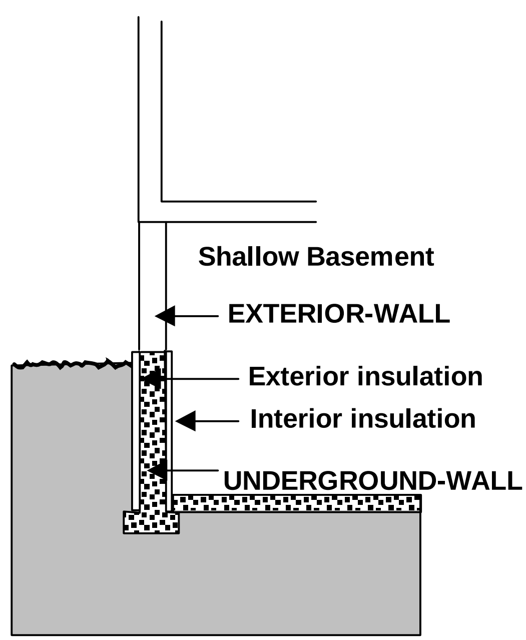
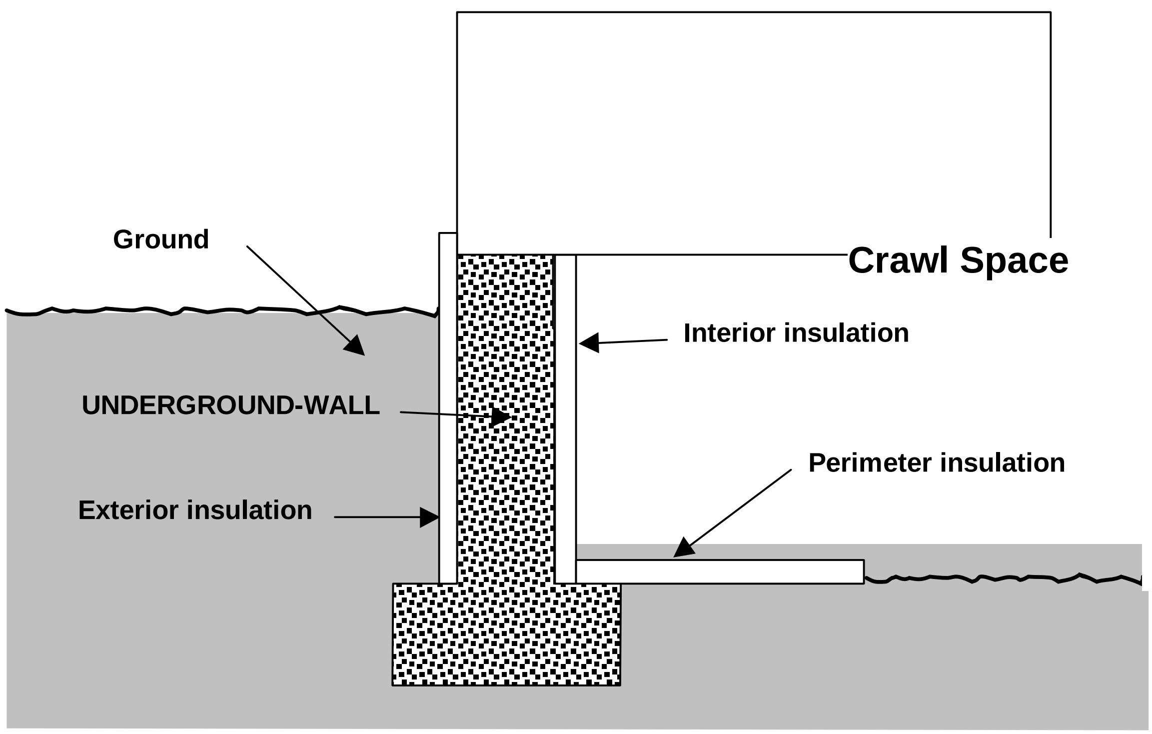


Table 3: Perimeter Conduction Factors for Crawl Space Walls*

Crawl Space Wall		
Wall Height	**Construction (see sketch for location of insulation)**	**PERIM-CONDUCT Btu/hr-F-ft (W/m-K)**
2 ft	R-0 (uninsulated), concrete	1.29 (2.23)
	R-5 exterior, concrete	0.93 (1.61)
	R-10 exterior, concrete	0.87 (1.95)
	R-5 interior, concrete	0.97 (1.50)
	R-10 interior, concrete	0.91 (1.57)
	R-5 interior; R-5 4-ft perimeter, concrete	0.73 (1.26)
	R-10 interior; R-10 4-ft perimeter, concrete	0.68 (1.18)
	R-0, wood frame	1.00 (1.73)
	R-11, wood frame	0.88 (1.52)
	R-19, wood frame	0.86 (1.49)
4 ft	R-0 (uninsulated), concrete	1.28 (2.21)
	R-5 exterior, concrete	0.71 (1.23)
	R-10 exterior, concrete	0.59 (1.02)
	R-15 exterior, concrete	0.54 (0.93)
	R-20 exterior, concrete	0.50 (0.86)
	R-5 interior; R-5 4-ft perimeter, concrete	0.64 (1.11)
	R-10 interior; R-10 4-ft perimeter, concrete	0.58 (1.00)
	R-0, wood frame	0.83 (1.44)
	R-11, wood frame	0.59 (1.02)
	R-19, wood frame	0.55 (0.95)

*Source: Y.J.Huang, L.S.Shen, J.C.Bull and L.F.Goldberg, "Whole-House Simulation of Foundation Heat Flows Using the DOE-2.1C Program," ASHRAE Trans. 94 (2), 1988, updated by Y.J. Huang, private communication.



From the Building Energy Simulation User News, Vol. 19, No. 1 (Spring 1998)

Orientation Information for Interior Walls

by
Fred Winkelmann

Question:

In DOE-2, is it necessary to include explicit orientation information (X, Y, Z, AZIMUTH, TILT) for interior walls when studying daylighting?

Answer:

Only the TILT value is needed. It is used to determine whether the surface is a floor, wall or ceiling. This information is then used in the room interreflection calculation in the following way. Light moving upward through a window is reflected off of the ceiling and the upper part of walls. Light moving downward through a window is reflected off of the floor and the lower part of the walls.

This is the so-called "split-flux" calculation. It is crude since it neglects the X, Y, Z and azimuth of the surfaces. However, it gives a fairly good interreflected illuminance estimate for rectangular rooms with a depth less than three times floor to ceiling height.

From the Building Energy Simulation User News, Vol. 17, No. 3 (Fall 1996)

Using DOE-2 to Study Apartment Indoor Temperatures During the July 1995 Chicago Heat Wave

by
Joe Huang

Although DOE-2 is generally used to analyze building energy consumption, it can also be used to evaluate thermal conditions in buildings without air-conditioning. This article describes the use of DOE-2 to investigate conditions in apartment buildings during the July 1995 Heat Wave in Chicago, and determine to what degree the poor thermal characteristics and improper operations of the buildings might have contributed to the death toll. The July 1995 Chicago Heat Wave created a great deal of human discomfort and, by latest estimates, increased deaths in Cook County by over 700 over a five day period. Epidemiological studies have uncovered a number of socio-economic, cultural, institutional, and physiological factors, but the role of the building and its interior conditions have been largely unexamined.

Studies of mortality during heat waves have found a heat index threshold above which deaths increase rapidly, and that the duration of the heat wave, increased humidity, high minimum temperatures, and low wind speeds all contribute to increased deaths. There is also typically a one-day time lag between the peaks in the heat index and deaths. In the recent Chicago Heat Wave, most of the victims were older, infirm residents living on the top floors of inner-city apartments with no air-conditioning.

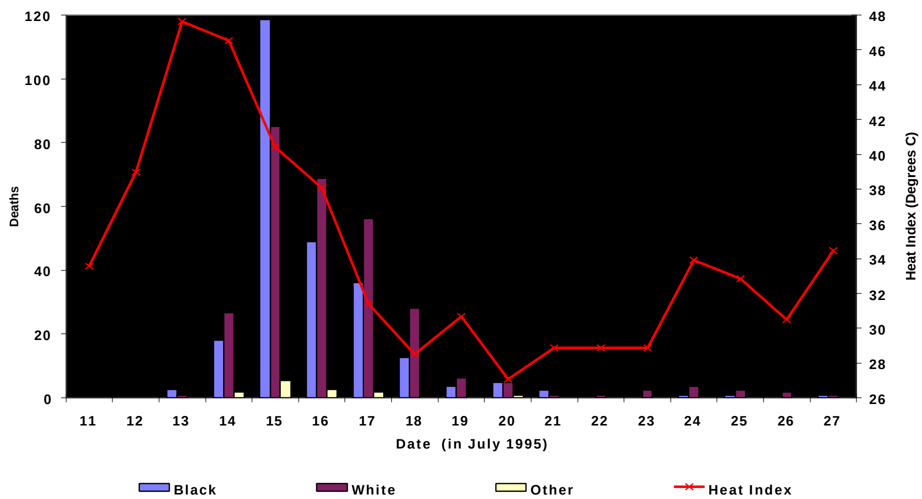


Figure 1: Chicago July 1995 Heat Storm's Fatal Impacts (source : *Global Change,* February 1996)

To researchers in building physics, such weather and building conditions are characteristically those that would produce abnormally high indoor temperatures. This was confirmed through DOE-2 simulations of four prototypical apartment buildings of different vintages (pre-1940s, 1960s, 1970s, and 1980s) with building characteristics and conservation levels based on the Residential Energy Consumption Survey (RECS) for multi-family buildings in the North Central Region.

DOE-2 was used to simulate indoor conditions in the prototypical apartment buildings during the July 1995 Heat Wave in the absence of air-conditioning, first with the windows closed, and then opened for ventilation whenever outdoor temperatures were lower. To study the benefits of potential conservation strategies, the simulations were repeated with additional ceiling insulation, light-colored roofs, and lowered window shading coefficients.

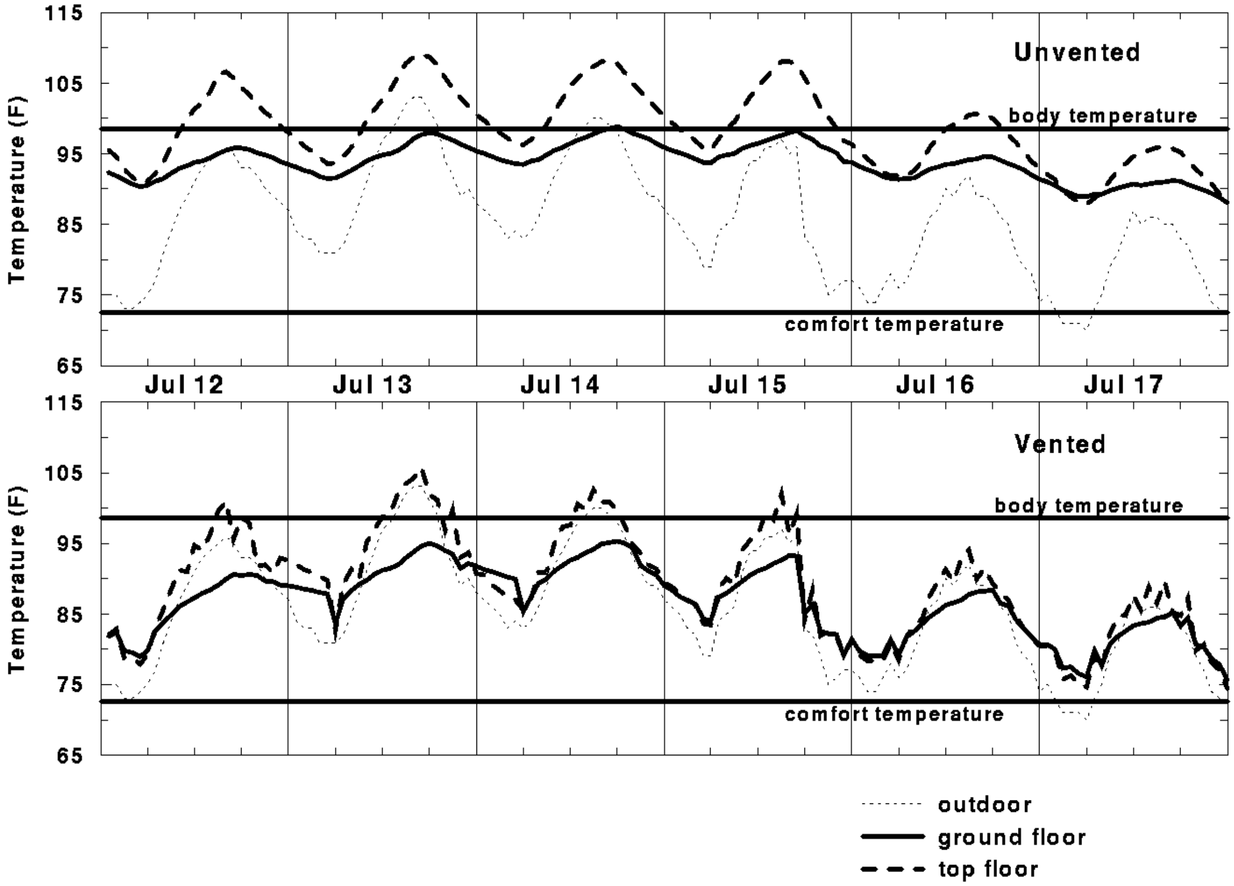


Figure 2: DOE-2-calculated Indoor temperatures in a typical 1940's apartment building in Chicago during the July 1995 Heat Wave

The results are presented as plots of temperature history or temperature and humidity on a psychrometric chart (see Figures 2 and 3). If the buildings were unventilated, as often reported as the case, the indoor temperature would reach as high as 108F on the top floors of the pre-1940s buildings and above human body temperature 80 percent of the time over the peak three days. Conditions in the 1970s apartment building would be even worse, with the *average temperature* of 108F over the same three-day period! Due to their greater mass and insulation, these buildings would remain hot for days after the peak air temperatures had already passed.

The simulations show that the single most important strategy to prevent excessive overheating during a heat wave is ventilation. Under such conditions ventilation would not make the buildings comfortable but would prevent them from acting like solar ovens and keep temperatures indoor close to or below that outdoors. In older, un-insulated buildings, adding ceiling insulation and lightening the roof color would have an appreciable impact on improving conditions in top floor apartments. However, in newer buildings weatherization would make minimal impact.

The prevention or reduction of mortality during an intense heat wave should be viewed as a form of disaster control. Due to the public outcry over the 1995 Heat Wave, the city of Chicago has announced a plan in the case of future heat waves, but the plan so far focuses on providing warnings, checking on residents, and moving people to a "cool room". This preliminary study suggests the dangers can also be lessened by improving the thermal conditions and operation of the buildings.

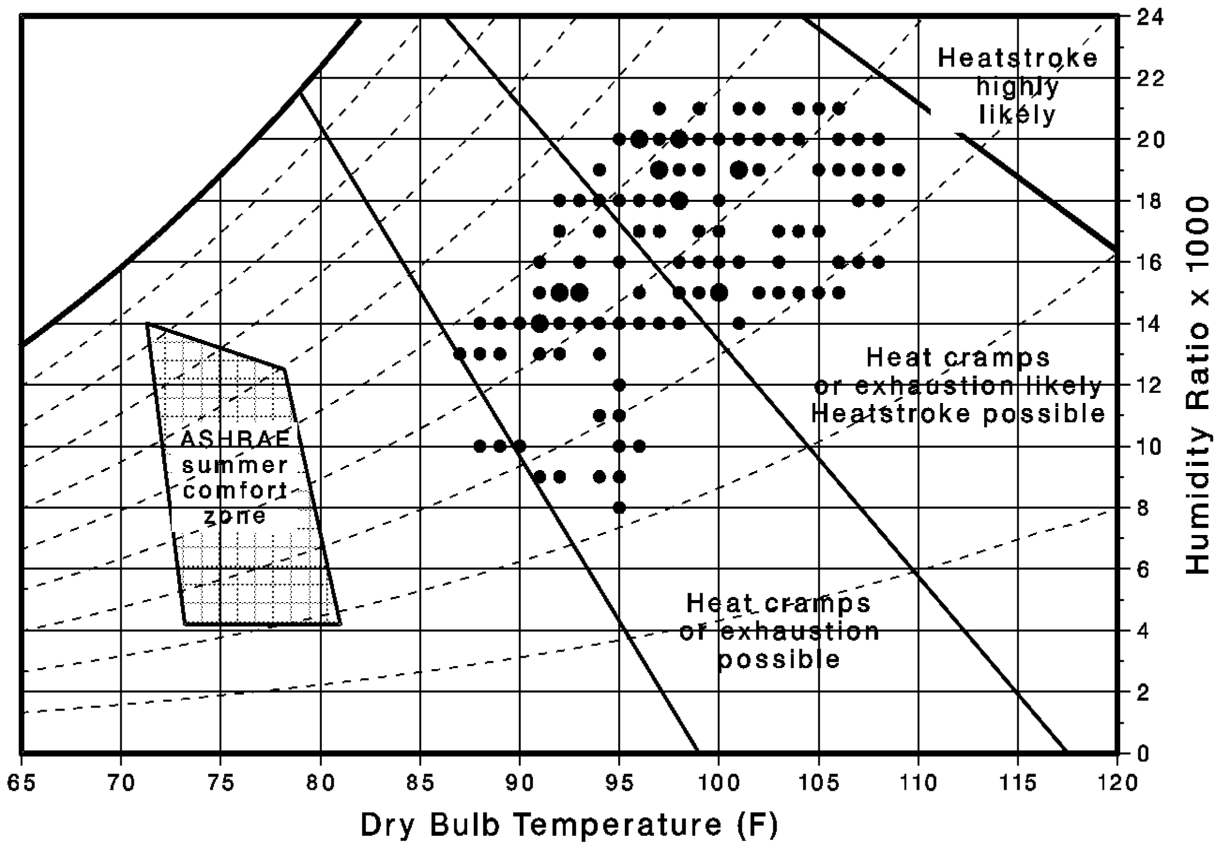


Figure 3: **Psychrometric plot of DOE-2 calculated indoor temperatures on top floor of unventilated 1940's apartment in Chicago during the July 1995 Heat Wave**

References

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3. Y.J. Huang 1995. "DOE-2 analysis of indoor temperatures in typical apartment buildings during the July 1995 Chicago summer Heat Wave," office memorandum, Lawrence Berkeley National Laboratory.
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From the Building Energy Simulation User News, Vol. 17, No. 1 (Spring 1996)

DOE-2 VALIDATION: Daylighting Dimming and Energy Savings: The Effects of Window Orientation and Blinds

by

Lynn Schrum and Danny Parker

Abstract
The Daylighting Test Facility (DTF), located at the Florida Solar Energy Center, was used to study daylight dimming systems and to learn how orientation and blinds affect energy savings. To evaluate the impact of blinds on dimming savings, the energy consumption was compared in two pairs of offices for all four window orientations: north, south, east and west. One office in each pair had blinds in a fixed position (down and open) and the other office had no blinds. From September through December of 1994, data were collected on the north- and south-facing offices. The DTF was rotated 90 degrees and data were collected from January through April for east- and west-facing offices. The DTF was also modeled on DOE-2.1 and the predicted energy usage was compared to the actual data.. The study showed that daylight dimming systems can provide significant energy savings of from 24% to 51% depending on the orientation and whether the office had blinds. The research suggest adjustments be made to parameters used with the DOE 2.1E daylighting model to improve the accuracy of its predictions.

Introduction
Until 1900, most buildings were "daylit" in the sense that daylight was the major source of daytime illumination. Due to the electricity use and increased cooling load that is created by electric lighting, there is a renewed interest in daylighting commercial buildings. Numerous theoretical studies have shown significant potential for energy savings in daylit buildings [1]. In order for a daylit building to realize energy savings, the electric lighting system must be manually switched in an effective fashion or else be linked to some type of integrated control system. The shortcomings of reliance on manual control are extensively documented in the literature [2]. A study by Hunt and Cockram [3] showed that continually occupied offices experienced little manual switching during occupancy. Most of the switching was at the start and the end of the work day. Thus, reliable savings are likely only with automated controls.

One type of dynamic lighting control system available is the continuous dimming system which constantly adjusts the electric lighting level based on the amount of daylight available. A continuous dimming system consists of a photosensor that provides the control signal that is used by the dimming electronic ballast to vary the light level according to changes in daylight availability. These systems seem attractive since they reduce the use of electric light automatically without occupant intervention.

Significance of the Problem
Computer simulations such as DOE-2 and other programs [4] can be used to predict energy savings for such continuous dimming systems. However, these simulations do not accurately account for human behavior such as seasonal blind adjustment related to window orientation. The use of automatic daylight controls and potential energy savings has been studied [5], but the position of the blinds was not taken into account. Studies on window blind usage show that people use window blinds to block solar radiation (both as a source of localized overheating as well as glare) [6,7]. However, typically, occupants did not change blind positions within a day. Preference for window blind position seems to be based on long-term perceptions of solar radiation or other factors. Other considerations such as privacy and security may be ancillary concerns.

Little data have been collected *in situ* to quantify the energy savings as a result of daylight dimming systems. Actual savings may vary depending on the window orientation and window management strategies. A metered study conducted by Lawrence Berkeley National Laboratory [8] showed the energy savings were less in the south daylit zone than in the north daylit zone due to the occupants using drapes to reduce glare and thermal discomfort on the south orientation. A National Bureau of Standards study [9] found that window area does not influence lighting load as strongly as the type of window system. A window system may include window coatings, external shading devices, and internal shading devices such as blinds. However, preliminary data of an on-going study [10] in a Wisconsin commercial building showed that savings were greatest on the south side of the facility even though occupant manipulation of the window blinds did reduce savings. The building being monitored had windows on all four sides with a dimming system and blinds. During the winter, the amount of light entering through the east and south faces was so great that occupants often manipulated the blinds to reduce the heat, light, and glare. The report also stated that many occupants on the north side often had their blinds fully raised in order to have an unrestricted view throughout the day.

The contrary results of the limited research performed so far underscore the need for a more rigorous evaluation of the effects of orientation on daylighting system performance. The purpose of this research is to monitor the electric lighting energy usage of eight offices with windows and a continuous dimming system.

Daylighting Test Facility

Test Site Description

The test site, the Daylighting Test Facility (DTF), is located at the Florida Solar Energy Center, Cape Canaveral, Florida (latitude 28^o, longitude 80^o). Eight offices are located within the test site. The offices vary in size, number of windows and window orientation as shown in Table 1 for both phases of testing. All windows are 0.84m x 0.71m (2'9" x 2'4") located 1.2m (4') from floor. The ceiling height is 2.3m (7'9"). The trailer can be rotated so that the north- and south-facing windows become east- and west-facing windows. The offices contain work desks and other furnishings usually found in the typical office environment. Each office has a video display terminal; visual tasks include reading, writing, drafting, and typing. The interior floor surface is brown carpet with an approximate reflectance of 0.20. The four interior walls are beige and have a reflectance of 0.45. The ceiling is finished off-white with a reflectance of 0.70. The exterior surface on the sides of the trailer is grass with no obstructions. The windows consist of double pane clear glass 1/8" thick with a light gray tint. The measured visible transmittance of the single pane windows is 0.67. Each window has one-inch mini-blinds that are white and have a reflectance of ~0.70. The blinds remained fixed to eliminate occupant related variation. The blinds remained down with the slats at 90 degrees. All offices have blinds except two offices that were intentionally left without blinds to examine their relative effect.

Electric Lighting System

Each office has two or three two-lamp ceiling-mounted wrap-around prismatic fluorescent luminaires. Two T-8 lamps (4100^oK) and one integrally controlled electronic ballast are used in each luminaire. Manufacturer's data suggest that the ballasts can be dimmed over a range from 100% to approximately 20% of full power. The luminaires are four feet on center and operate on 120 Vac. The lighting design setpoint for each office was 538 lux (50 footcandles).

Table 1

Office	Dimensions	Number of Windows	Orientation	
			Phase I	Phase II
A	3.4m x 4.0m (11' x 13')	2	North and east	West and north
B	3.4m x 4.0m (11'3" x 13')	2	South and east	East and north
C	2.2m x 2.9m (7'1'" x 9'7")	1	South	East
D	2.2m x 2.9m (7'1" x 9'7")	1	South	East
E	3.4m x 4.3m (11'3" x 14')	2	Both south	Both East
F	3.4m x 4.3m (11' x 14')	2	Both north	Both West
G	2.3m x 2.7m (7'9" x 9')	1	North	West
H	2.3m x 2.7m (7'9" x 9')	1	North	West

Photosensors

The dimming photosensor is a ceiling mount, low voltage photocell that interfaces with an electronic ballast. The sensor is used to control the output of light based on the availability of natural light and on the required task illumination level. The photosensor has a Fresnel lens which allows the sensor to measure light levels uniformly across a 60 degree field of view. An analog output to the control ballast provides a dimming range from 10% to 100% illumination output.

Instrumentation

Electrical Measurements

The lighting power and current to the four branch circuits serving the offices are individually monitored with watt-hour transducers with a current transformer to supply the input. These transducers accurately measure true root mean square (RMS) power and current regardless of any current wave shape distortion. All the transducers are mounted in a central location in the trailer. The watt-hour transducers are factory calibrated with an accuracy of ± 1.0%.

Photometric Measurements

Light levels in the offices are monitored with color- and cosine-corrected photometers. One photometer is mounted in each office at desktop height, two-thirds away from the window wall. The photometers were mounted directly below the ceiling-mounted ambient sensor used by the dimmable lighting system to control the electric light levels. Global horizontal insolation data are concurrently taken on a horizontal plane at the building using silicon cell pyranometers.

Data Acquisition

All measured values are recorded using a datalogger (12-bit precision). The datalogger scans all instrumentation every ten seconds with integrated averages output to storage at fifteen-minute intervals. Data is transferred daily from the DTF to FSEC's mainframe computer. Data are then archived and daily plots produced to describe system performance on the previous day.

Experimental Procedure

Data for the north- and south-facing offices were collected for four months (September - December) to cover half the seasonal daylight availability cycle. At the end of this cycle, the trailer was rotated 90 degrees so that the windows are oriented east and west, respectively. This was accomplished on January 11, 1995. Data were collected for the east- and west-facing offices for four months (January-April).

Discsussion of Measured Results

Illumination and power consumption data were taken between September 1 and December 31, 1994 for the north- and south-facing windows. The same data were taken between January 17 and May 16, 1995 for the east- and west-facing windows. Data analysis concentrated on the hours of 6 AM and 6 PM since it is more expensive to supply and use energy during this time. This is also the most common period during which office lighting systems are used in commercial facilities.

The lighting system was powered 24 hours a day so that the percent energy reduction was calculated by using the nighttime data as the baseline. The nighttime monthly average wattage for each office was calculated by estimating the mean electrical demand between the hours of 10 PM and 6 AM. The average was multiplied by twelve to compare to the 12-hour daytime period. The total kWh was also plotted for each month between the hours of 6 AM and 6 PM. Table 2 shows the total monthly kWh data taken of the dimming system over the entire period from September 1, 1994 to December 31, 1994 for the four north- and south-facing interior offices.

Table 3 shows the total monthly kWh data for the period from January 17 to May 16, 1995 for the four east- and west-facing interior offices. The daytime data was divided by the baseline data to obtain the percent energy reduction. For the purposes of the analysis, these calculations assume that the lights would be on continuously between the hours of 6 AM and 6 PM.

Table 4 shows a summary of the percent lighting energy reduction for the same period. The energy reduction ranged from 24% to 45% depending on orientation and blind condition. The south-facing office with no blinds had the lowest power consumption over the test period with a 45% lighting energy reduction for the period. The north-facing office with blinds had the highest power consumption with a 24% energy reduction. Blinds show a 7% effect on the energy savings for both orientations.

Table 2
Monthly Lighting Energy Consumption For Four Offices North-South Orientation (Total kWh)

Condition	Office	Month				
		Sept	Oct	Nov	Dec	Total
North-No Blinds	G	59	71	71	76	278
North-Blinds	H	62	79	74	78	293
South-No Blinds	C	52	68	68	70	259
South-Blinds	D	56	75	73	79	283

Table 3
Monthly Lighting Energy Consumption For Four Offices East-West Orientation (Total kWh)

Condition	Office	Month				
		Jan	Feb	Mar	Apr	Total
East-No Blinds	C	67	81	74	72	255
East-Blinds	D	61	72	65	64	304
West-No Blinds	G	65	78	71	70	278
West-Blinds	H	62	73	67	64	270

Table 4
Percent Lighting Energy Reduction* North and South Offices

Condition	Office	Month				
		Sept	Oct	Nov	Dec	Total
North-No Blinds	G	42%	30%	30%	21%	31%
North-Blinds	H	35%	19%	25%	18%	24%
South-No Blinds	C	54%	47%	42%	37%	45%
South-Blinds	D	48%	39%	38%	26%	37%

* Energy reduction is based on assuming the lights would have been on continuously between the hours of 6 AM and 6 PM. The baseline data was taken as an average of the system wattage between the hours of 10 PM and 6 AM.

Table 5
Percent Lighting Energy Reduction* East and West Offices

Condition	Office	Month				
		Jan	Feb	Mar	Apr	Total
East-No Blinds	C	44%	47%	49%	51%	48%
East-Blinds	D	22%	27%	32%	37%	30%
West-No Blinds	G	28%	31%	32%	34%	31%
West-Blinds	H	33%	33%	34%	41%	35%

* Energy reduction is based on assuming the lights would have been on continuously between the hours of 6 AM and 6 PM. The baseline data was taken as an average of the system wattage between 10 PM and 6 AM.

Table 5 shows a summary of the percent energy reduction for the east-west orientation during the period described. The energy reduction ranged from 22% to 51% depending on the orientation and blind condition. The east-facing office with no blinds had the highest period energy reduction of 48%. For this orientation, blinds had an 18% effect on power consumption. The west-facing offices did not yield expected results. The office with blinds had a 3% higher power consumption.

To verify the west-facing office data, the blind condition was switched. The blinds were removed from one west-facing office and installed in the control office (office without blinds). The data taken for one month from June 17 to July 17 showed an energy reduction of 44.9% for the office without blinds and 18% for the office with blinds. These results indicated that once the blind condition was switched, the blinds did make a significant difference of 26.8 percent. This data led researchers to believe that the dimming system was not working properly in the office without blinds during the four-month test period. Since these data were taken during the summer solstice, it is expected that the energy reduction would be higher than the test period.

Simulation Analysis

The facility was modeled and compared to the field data with the DOE-2.1E program, which evaluates energy use, peak loads, and energy cost; it allows the user to predict the impact of daylighting on electric lighting energy consumption.

The DOE-2.1E daylighting calculation simulates control of lighting fixtures in response to the level of natural lighting from the sun, sky, and reflection off the inside surfaces of the space. Input parameters include window size and orientation, glass transmittance, inside surface reflectance of the space, sun-control devices such as blinds and overhangs, and the luminance distribution of the sky. Continuously dimming control systems and window shade management can be modeled.

The eight offices were modeled in the north-south orientation. Parameters that affect the daylighting calculations include window visible transmittance, blind transmittance, blind schedule, window location in the wall and orientation. The glass visible transmittance at normal incidence was measured at 0.67. A user-specified blind visible transmittance schedule with values between 0.0 and 1.0 multiplies the glass transmittance on an hourly basis depending on the blind coverage and slat position. A value of 0.0 indicates the blind is down with the slats closed and 1.0 is a blind completely up. Since the blinds were fixed, the blind schedule was set at 0.23 for the simulation period. The value of 0.23 is an estimate of the blind transmittance when the blinds are down and the slats are open at 90 degrees.

The DOE-2.1E input file for the DTF simulations is available from the authors by request. This input file was run for the north-south orientation with a building azimuth of 0 degrees. To simulate the east-west orientation the building azimuth was changed to 270 degrees. The simulations were run using typical meteorological year (TMY) weather data recorded on an hourly basis at Orlando, FL.

The kWh usage for the offices, which was predicted by DOE-2.1E, was compared to the actual DTF data; tables 6 and Table 7 show a comparison. For total lighting energy consumption, DOE-2 agreed with measurements to 17.4% or better. The agreement was best for cases without blinds, with an average absolute discrepancy of 3.9%. With blinds, the average absolute discrepancy was 11.5%. In general, DOE-2.1E overpredicted the lighting energy use in offices with blinds, implying that, in this case, the measured dimming exceeds that predicted. As a result of this analysis, it was concluded that the blind schedule and the visible transmission of the blinds are important parameters that affect the predicted power consumption.

DOE-2.1E makes two assumptions about blind transmission that may account for the discrepancy:

1) The blind transmittance is independent of the angle of incidence of light hitting the blind.

2) The blind is a perfect diffuser.*

Although these may be poor assumptions, there are very little data on the transmission angular dependence for common blind types

Summary

The study shows that daylight dimming systems provided significant energy savings that ranged from 22% to 51% depending on orientation and whether the office had blinds. The east-facing office with no blinds had both the highest energy reduction of 51% and the lowest monthly energy reduction of 22%. Although the blinds were fixed, they had a 7% average reduction on the energy savings for both the north- and south-facing offices. The east-facing offices had an 18% blind effect. The data taken one month after the blind condition was switched in the west-facing offices indicated the energy reduction may be similar to the east-facing offices. Use of DOE-2.1E indicated that parameters such as window and blind visible transmission and blind schedule can change the predicted energy consumption. In all interior offices with blinds and the north-facing no blind condition, DOE-2.1E agreed with measurements to within 17%, which indicated that program estimates for daylight dimming savings might be be conservative for offices with blinds operated like those in our study.

Follow-Up

A blind usage study will be conducted in a large facility on a statistically valid sample of offices to examine how occupants use their blinds related to window orientation and season. This research may lead to the development of a blind usage multiplier for energy simulation programs like DOE-2.

**[Editor's note: DOE-2.2, the next version of DOE-2, contains an improved blind model that is expected to give even better agreement with daylighting measurements. In this model you enter the slat characteristics (like width, separation, reflectance and angle), from which the program calculates the incidence-angle-dependent transmittance taking interreflection between the slats into account. This new model was developed by Hans Simmler of EMPA, the Swiss Federal Materials Testing Laboratory in Dubendorf, Switzerland, and Uwe Fischer of the University of Karlsruhe, Germany.]*

Table 6
DTF/DOE kWh Data Comparison North-South Orientation

Month	North No Blinds Office G		North Blinds Office H		South No Blinds Office C		South Blinds Office D	
	DTF	DOE	DTF	DOE	DTF	DOE	DTF	DOE
September	59.2	65.9	62.3	84.4	52.4	60.8	56.4	78.0
October	73.7	74.7	79.0	88.7	68.4	64.4	75.5	78.0
November	71.3	77.2	74.1	86.8	68.0	63.4	72.8	74.1
December	76.2	80.7	77.6	90.0	69.9	68.1	78.5	78.7
Total	280.4	298.5	293.0	349.9	258.6	256.6	283.0	308.8
Percent Difference DTF/DOE	+ 6.0		+ 16.3		-0.8		+ 8.3	

Table 7
DTF/DOE kWh Data Comparison East-West Orientation

Month	East No Blinds Office C		East Blinds Office D		West No Blinds Office G		West Blinds Office H	
	DTF	DOE	DTF	DOE	DTF	DOE	DTF	DOE
January	66.8	70.7	81.1	84.5	74.2	71.6	71.6	86.4
February	60.5	59.9	71.9	74.8	65.4	60.6	64.0	76.8
March	65.3	77.5	78.0	80.5	70.8	64.2	70.1	83.1
April	62.2	76.5	72.7	76.5	67.1	59.6	63.5	79.6
Total	255.1	253.3	304.2	316.4	277.8	255.8	269.2	325.9
Percent Difference DTF/DOE	-0.71		+3.9		-7.9		+17.4	

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From the Building Energy Simulation User News, Vol. 16, No. 1 (Spring 1995)

Switch-off Dimming System

by
Fred Winkelmann

Question:

How can I model a continuous dimming system in DOE-2 in which the lights dim to some low value and then turn off? The option LIGHT CTRL TYPE1 (or LIGHT CTRL TYPE2) = CONTINUOUS dims to MIN LIGHT FRAC and MIN POWER FRAC but stays at those values if the daylight illuminance increases. Instead, I want the lights to turn off completely at this point because this reduces electricity use.

Answer:

An Input Function that does this has been devised by Monica Bosler of Consulting Engineers, Inc., Tulsa, OK. An example of the function (for one daylighting reference point) is as follows. The same function will also work for two reference points.

```
INPUT LOADS ..
...
SPACE-1   =SPACE
           ...
           DAYLIGHTING = YES
           LIGHT-REF-POINT1 = (24,24,2.5)
           LIGHT-SET-POINT1 = 60
           LIGHT-CTRL-TYPE1 = CONTINUOUS
           ZONE-FRACTION1   = 1.0
           MIN-LIGHT-FRAC   = 0.10
           MIN-POWER-FRAC   = 0.283
           DAYL-LTCTRL-FN   = (*NONE*,*SWITCH-OFF*) ..
...
END ..
FUNCTION  NAME = SWITCH-OFF ..
ASSIGN    MPF  = MIN-POWER-FRAC $ min power fraction
          PRF  = POWER-RED-FAC  $ power reduction factor
          NREFP= NREFP          $ number of reference points
          ZF1  = ZONE-FRACTION1 $ fraction of zone for 1st ref pt
          ZF2  = ZONE-FRACTION2 $ fraction of zone for 2nd ref pt
          FP1  = FPHRP1         $ power fraction for 1st ref pt
          FP2  = FPHRP2 ..      $ power fraction for 2nd ref pt
CALCULATE ..
      IF(FP1.LE.MPF) FP1 = 0
      PRF = FP1*ZF1 + 1 - ZF1
      IF(NREFP.LT.1.5) RETURN
      IF(FP2.LE.MPF) FP2 = 0
      PRF = PRF + FP2*ZF2 - ZF2
      END
END-FUNCTION ..
COMPUTE LOADS ..
...
```

Note: if there are two reference points, this function requires that both LIGHT CTRL TYPE1 and LIGHT CTRL TYPE2 = CONTINUOUS. In a future version of DOE-2 this type of control will be added as LIGHT CTRL TYPE1 (or LIGHT CTRL TYPE2) = CONTINUOUS/OFF.

From the Building Energy Simulation User News, Vol. 16, No. 1 (Spring 1995)

Metric Unit Values for the ENERGY-RESOURCE Command

by
René Meldem

Question:

I did a metric DOE-2.1E run and the numbers in Plant reports PS-B (Monthly Utility and Fuel Use Summary) and PS-F (Energy Resource Peak Breakdown by End Use) made no sense whatsoever.

Answer:

The problem is a bug in the program when metric units are used. The work-around is to input an ENERGY-RESOURCE command for each energy resource being considered in your building (see DOE-2 Supplement (2.1E) , p.4.5-4.7). Examples for various resources (natural gas, steam, chilled water, etc.) are shown below. Note that, even though you are dealing with metric input, the units for the ENERGY/UNIT keyword are Btu/unit, not Wh/unit.

Plant ENERGY-RESOURCE Commands for Metric Input

```
ENERGY-RESOURCE
RESOURCE = NATURAL-GAS
ENERGY/UNIT = 37102.34        $  BTU/M3, based on 1M3 = 10.871 kWh $
UNIT-NAME = M3
DEM-UNIT-NAME = M3/H ..

ENERGY-RESOURCE
RESOURCE = STEAM
ENERGY/UNIT = 3413000         $ BTU/MWh  $
UNIT-NAME = MWH
DEM-UNIT-NAME = MW ..

ENERGY-RESOURCE
RESOURCE = CHILLED-WATER
ENERGY/UNIT = 3413000         $ BTU/MWh  $
UNIT-NAME = MWH
DEM-UNIT-NAME = MW ..

ENERGY-RESOURCE
RESOURCE = ELECTRICITY
ENERGY/UNIT = 3413            $ BTU/kWh  $
UNIT-NAME = KWH
DEM-UNIT-NAME = KW ..

ENERGY-RESOURCE
RESOURCE = LPG
ENERGY/UNIT = 25198.18        $ BTU/liter based on 7.383 kWh/liter $
UNIT-NAME = LITERS
DEM-UNIT-NAME = LITERS/HR ..

ENERGY-RESOURCE
RESOURCE = FUEL-OIL
ENERGY/UNIT = 36597.6         $ BTU/liter based on 10.723 kWh/liter $
UNIT-NAME = LITERS
DEM-UNIT-NAME = LITERS/HR ..

ENERGY-RESOURCE
RESOURCE = DIESEL-OIL
ENERGY/UNIT = 36597.6         $ BTU/liter based on 10.723 kWh/liter $
```

```
UNIT-NAME = LITERS
DEM-UNIT-NAME = LITERS/HR ..

ENERGY-RESOURCE
RESOURCE = COAL
ENERGY/UNIT = 27100.6         $ BTU/kg based on 7.94 kWh/kg $
UNIT-NAME = KILOS
DEM-UNIT-NAME = KILOS/HR ..

ENERGY-RESOURCE
RESOURCE = METHANOL
ENERGY/UNIT = 16754.4         $ BTU/liter based on 4.909 kWh/liter $
UNIT-NAME = LITERS
DEM-UNIT-NAME = LITERS/HR ..

ENERGY-RESOURCE
RESOURCE = OTHER-FUEL
ENERGY/UNIT = 3413            $ BTU/kWh  $
UNIT-NAME = KWH
DEM-UNIT-NAME = KW ..
```

From the Building Energy Simulation User News, Vol. 16, No. 1 (Spring 1995)

Changing the Holiday List in DOE-2

by
Sam C. M. Hui

Introduction

In full hour-by-hour building energy simulation programs like DOE-2, there is usually a holiday list to represent the general holidays of the calendar year under consideration. In DOE-2, the holiday list is designated by default as the ten official holidays of the United States [Ref. 1].

Up to and including the DOE-2.1D version, it was not possible to change the holiday list without modifying the FORTRAN source code [Ref. 2]. This was inconvenient for those of us working on simulation exercises in other countries and made it impossible to assess the effects of holidays on building energy simulation and analysis.

This problem was recognized by the program developers and in the latest release (DOE-2.1E) a new command "ALT HOLIDAYS" was introduced. It allowed non-U.S. program users to change the default U.S. holiday list [Ref. 1]. It took a "month-day" pair like the RUN PERIOD command and allowed an input of up to 40 pairs in each run [Ref. 3]. However, if you want to prepare a BDL input file for simulations with a number of different calendar years, you might want to define a set of general relationships for your own local holidays; ALT HOLIDAYS was not flexible enough to meet these needs.

To tackle these problems, we used "user-defined input functions" to change the holiday list and to offer a flexible way of defining the holidays. The author has prepared some simple input functions for Hong Kong and has tested them with both the "D" and "E" versions of DOE-2. Holiday adjustments are important to the simulation results because the internal loads (occupancy, lighting and equipment), which are essential components of building energy consumption, are directly affected by the changes in day schedule.

Methodology

The Input Function feature, first introduced in DOE-2.1D, allows you to modify DOE-2 LOADS and SYSTEMS calculations without recompiling the program [Ref. 1]. However, before writing the input functions and making them work, you must understand the simulation variables, algorithms and locations of the final calculations. This can best be done by examining the simplified program flowcharts and algorithms of DOE-2 [Ref. 1 & 4]. However, there is no guarantee that you can modify every variable in the way you want and perform the desired changes to the simulation procedures. Careful examination of the hourly reports from DOE-2 are often needed to see if the desired results can be achieved. Fortunately, with a number of trials (and errors), the author has created the input functions for changing the holiday list for Hong Kong.

To define your own holiday list, you should note the schedules that will be affected by the day schedule (values from 1 to 8). The day schedule defines weekdays (1 to 7 for Sunday to Saturday) and holiday (8); it is determined by the "HOLIDA" subroutine in LOADS subprogram.

Two input functions are introduced in the hourly loop to carry out the changes:

1. HOLIDAY test for and change every schedule value on a holiday.
2. HOLRESET reset schedule values of holidays if they have been changed by HOLIDAY.

You must set the HOLIDAY keyword in the BUILDING LOCATION command to "NO" and declare the above two functions under this command so that they are called as "building before" and "building after" functions respectively. The command can be written like this:

```
B-L   ALT=33  G-A=49000  HOL=NO  D-S=NO  AZ=0
      FUNCTION=(*HOLIDAY*,*HOLRESET*)   ..
```

It should be noted that not all variables are passed between the LOADS, SYSTEMS and PLANT programs in DOE-2 [Ref. 5]. If the BDL input file also has SYSTEMS and PLANT sections, it is essential that similar input functions are specified respectively in those sections. For SYSTEMS, the location of the input functions is important; it is necessary to place the first user function as "plant before" function and the second reset function as "system after" function. For example, the command lines can be written like this:

```
SYST-1    =SYSTEM   S TYPE=SYS TYPE  S C=SYS CTRL  S A=SYS AIR
                    S FANS=SYS FAN  S T=SYS TERM  R A P=DUCT
                    Z N=(SP N,SP E,SP S,SP W,SP I,CORE,
                         RFSP N,RFSP E,RFSP S,RFSP W,RFSP I,RFCORE,
                         GFSP N,GFSP E,GFSP S,GFSP W,GFSP I,GFCORE,)
                    HEAT S=ELECTRIC  Z H S=ELECTRIC
                    S O=COINCIDENT  S R=1
             $ Add HOLRES2 in SYSTEM after loop
                    FUNCTION=(*NONE*,*HOLRES2*)  ..
PLT-1     =P A      S N=(SYST 1)
             $ Add HOLLID2 in PLANT begin loop
                    FUNCTION=(*HOLID2*,*NONE*)  ..
```

Holidays for Hong Kong

It is rather difficult to define a general set of equations for the public holidays in Hong Kong because there are holidays from the Western culture (such as Christmas and Easter) as well as from traditional Chinese culture (such as Chinese New Year and Dragon Boat Festival). Chinese holidays follow the lunar calendar and their calculations are not simple and straight-forward under the normal calendar.

The rules for determining the general holidays in Hong Kong and the dates of the holidays for the past decades have been studied [Refs. 6 and 7]. There are a total of 17 public holidays in Hong Kong each year (excluding Sundays). The number is greater than that for the default U.S. holidays (10 holidays only). But it should be noted that 5-day week is common in the United States, whereas 5-and-a-half day and 6-day weeks are common in Hong Kong.

A user function in DOE-2 has been established to determine the general holidays of Hong Kong for the years 1979 to 1993. The holiday list will be changed according to the year of simulation under consideration. An abstracted version of the input functions is shown in the Appendix. The first part is the "HOLIDAY" input function and the second part is the "HOLRESET" function.

The user functions were tested with both the "D" and "E" versions of DOE-2. They may be modified to change the holiday list for other locations. The basic syntax for writing the user functions is very similar to that of writing in FORTRAN.

Effects of Adjusting the Holidays

The effects of changing the default U.S. holidays to the Hong Kong local holidays were studied by carrying out DOE-2 simulations on a model office building (see [Ref. 8] for details of the model building). Weather data files in TMY format for the 15 years from 1979 to 1993 were used in the study and DOE-2.1D was used for the energy simulations.

Because all the weather files have 365 days, if a leap year is encountered then the 29th day of February is skipped, instead of the 31st day of December, so that the dates in the year are always correctly indicated. (If "Dec 31" is skipped there will be one-day difference after Feb 29, i.e. Feb 29 becomes Mar 1 and so on.)

Table 1 below shows a summary of the DOE-2 simulation results. You can see that the average difference in total annual building energy consumption between the two sets of holidays is about 1.7 percent. The variations of the differences in the 15-year period
are from 0.8 percent to 2.6 percent.

TABLE 1. Comparison of Simulation Results for Adjusting HK Holidays

Number of Holidays in Hong Kong		Annual Building Energy Consumption During Holidays (MWh)		Difference in MWh	Difference in percent
		In the U.S.	In Hong Kong		
1979	17	8051.31	7917.63	133.68	1.7%
1980	17	8108.76	7968.07	140.69	1.7%
1981	17	8165.05	7951.06	213.99	2.6%
1982	17	8074.10	7882.17	191.93	2.4%
1983	17	8070.80	7936.23	134.57	1.7%
1984	17	8221.65	8079.60	142.05	1.7%
1985	17	7957.48	7862.63	94.85	1.2%
1986	18*	7986.03	7884.36	101.67	1.3%
1987	17	8033.17	7885.50	147.67	1.8%
1988	17	8282.70	8140.24	142.46	1.7%
1989	17	8071.08	7909.31	161.77	2.0%
1990	17	8115.57	7991.60	123.97	1.5%
1991	17	8216.15	8066.72	149.43	1.8%
1992	17	8049.94	7876.07	173.87	2.2%
1993	17	8108.63	8047.40	61.23	0.8%
Average	17	8100.83	7959.91	140.92	1.7%

* = One additional holiday on Wednesday, October 22, 1986, for Queen's visit to HK.

The holiday list has significant influence on the simulation results because the internal loads (occupancy, lighting and equipment) and the system operation are directly affected by the changes in day schedule. It is essential that the same set of holidays is employed for comparative energy studies. It is also necessary to be aware of the variations in day schedule when comparing the simulation results for different calendar years at different locations.

Conclusion

The example demonstrated here for Hong Kong can be modified to change the holiday list for other locations. There is also the potential for creating input functions in a similar way to solve a wide range of problems associated with day schedule.

The "holidays" problem can be one of the sources that accounts for the difference in the simulation results. If we want to make sure that our comparison and validation are drawn on a fair basis, greater effort and care are required by modelers to look carefully on the calendar and day schedule under which the simulations are performed.

Acknowledgements

The author would like to thank Ellen Franconi and Fred Buhl of Lawrence Berkeley Laboratory for their useful advice and discussions. It is hoped that they can enjoy every one of their "holidays" no matter where they are!

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Appendix

```
$ Function to reset the holiday list in DOE-2 for Hong Kong
$ (the relevant load schedules will be changed)
FUNCTION NAME=HOLIDAY  ..
ASSIGN
      IDOW=IDOW
      IYR=IYR
      IMO=IMO
      IDAY=IDAY
      ISCHR=ISCHR
      ISCDAY=ISCDAY
      OCC=SCHEDULE-NAME(OCC-SCH)
      LTP=SCHEDULE-NAME(LGP-SCH)
      LTI=SCHEDULE-NAME(LGI-SCH)
      EQ1=SCHEDULE-NAME(EQP-SCH)
      INF=SCHEDULE-NAME(INF-SCH)
      XXX90=XXX90
      XXX91=XXX91
      XXX92=XXX92
      XXX93=XXX93
      XXX94=XXX94
      XXX95=XXX95  ..
CALCULATE  ..
C-------------- Set the schedule day to the day of the week
      ISCDAY=IDOW
C-------------- Set indicator to zero
      XXX90=0
C-------------- Skip if it is a Sunday
      IF (IDOW .EQ. 1)  GOTO 1000
C-------------- Determine which year is concerned
 50   IF (IYR .EQ. 1979)  GOTO 79
      IF (IYR .EQ. 1980)  GOTO 80
      IF (IYR .EQ. 1981)  GOTO 81
      IF (IYR .EQ. 1982)  GOTO 82
      IF (IYR .EQ. 1983)  GOTO 83
      IF (IYR .EQ. 1984)  GOTO 84
      IF (IYR .EQ. 1985)  GOTO 85
      IF (IYR .EQ. 1986)  GOTO 86
      IF (IYR .EQ. 1987)  GOTO 87
      IF (IYR .EQ. 1988)  GOTO 88
      IF (IYR .EQ. 1989)  GOTO 89
      IF (IYR .EQ. 1990)  GOTO 90
      IF (IYR .EQ. 1991)  GOTO 91
      IF (IYR .EQ. 1992)  GOTO 92
      IF (IYR .EQ. 1993)  GOTO 93
      GOTO 1000
C--------------------------------------------------------------------
C-------------- Chinese holidays in each year include:
C-------------- (1)  1st day of Chinese New Year
C-------------- (2)  2nd day of Chinese New Year
C-------------- (3)  3rd day of Chinese New Year
C-------------- (4)  Ching Ming Festival
C-------------- (5)  Tuen Ng (Dragon Boat) Festival
```

```
C-------------- (6)  Day following Mid-Autumn Festival (or Mid-Autumn
C--------------      if the day following is a Sunday)
C-------------- (7)  Chung Yeung Festival
C-------------- Easter holidays:
C-------------- (1)  Good Friday
C-------------- (2)  Day following Good Friday
C-------------- (3)  Easter Monday
C-------------- Queen's birthday
C-------------- a) For years 1979 - 1982:
C--------------    (1)  Queen's birthday (21 Apr or another day
C--------------         appointed in April)
C-------------- b) For years 1983 - 1993:
C--------------    (1)  Queen's birthday (2nd or 3rd Saturday in June)
C--------------    (2)  Monday following Queen's birthday
C-------------- Total nos. of general holidays:
C-------------- a) For years 1983-1993 =  17 days
C-------------- b) For years 1979-1982 =  16 days
C-------------- (* There is one additional holiday for Queen's visit
C--------------    to HK in 1986)
79   IF (IMO .EQ. 1 .AND. IDAY .EQ. 29)  GO TO 500
      IF (IMO .EQ. 1 .AND. IDAY .EQ. 30)  GO TO 500
      IF (IMO .EQ. 1 .AND. IDAY .EQ. 31)  GO TO 500
      IF (IMO .EQ. 4 .AND. IDAY .EQ. 5)  GO TO 500
      IF (IMO .EQ. 4 .AND. IDAY .EQ. 13)  GO TO 500
      IF (IMO .EQ. 4 .AND. IDAY .EQ. 14)  GO TO 500
      IF (IMO .EQ. 4 .AND. IDAY .EQ. 16)  GO TO 500
      IF (IMO .EQ. 4 .AND. IDAY .EQ. 21)  GO TO 500
      IF (IMO .EQ. 5 .AND. IDAY .EQ. 30)  GO TO 500
      IF (IMO .EQ. 10 .AND. IDAY .EQ. 6)  GO TO 500
      IF (IMO .EQ. 10 .AND. IDAY .EQ. 29)  GO TO 500
      GOTO 200
 ....
 .... {*** Other years from 1980 to 1992 are included here}
 ....
 ....
 93   IF (IMO .EQ. 1 .AND. IDAY .EQ. 22)  GO TO 500
      IF (IMO .EQ. 1 .AND. IDAY .EQ. 23)  GO TO 500
      IF (IMO .EQ. 1 .AND. IDAY .EQ. 25)  GO TO 500
      IF (IMO .EQ. 4 .AND. IDAY .EQ. 5)  GO TO 500
      IF (IMO .EQ. 4 .AND. IDAY .EQ. 9)  GO TO 500
      IF (IMO .EQ. 4 .AND. IDAY .EQ. 10)  GO TO 500
      IF (IMO .EQ. 4 .AND. IDAY .EQ. 12)  GO TO 500
      IF (IMO .EQ. 6 .AND. IDAY .EQ. 12)  GO TO 500
      IF (IMO .EQ. 6 .AND. IDAY .EQ. 14)  GO TO 500
      IF (IMO .EQ. 6 .AND. IDAY .EQ. 24)  GO TO 500
      IF (IMO .EQ. 10 .AND. IDAY .EQ. 1)  GO TO 500
      IF (IMO .EQ. 10 .AND. IDAY .EQ. 23)  GO TO 500
      GOTO 210
C-------------------------------------------------------------------
C-------------- General holidays in every year
C-------------- For years 1979 to 1982
C-------------- (1)  1st weekday in July
C-------------- (2)  1st Monday in August
 200  IF (IMO .EQ. 7 .AND. IDAY .EQ. 1 .AND. IDOW .NE. 1)  GOTO 500
      IF (IMO .EQ. 7 .AND. IDAY .EQ. 2 .AND. IDOW .EQ. 2)  GOTO 500
      IF (IMO .EQ. 8 .AND. IDAY .LE. 7 .AND. IDOW .EQ. 2)  GOTO 500
      GOTO 250
C-------------- For years 1983 to 1993
C-------------- (1)  Saturday preceding the last Monday in August
 210  IF (IMO .EQ. 8 .AND. IDAY .GE. 23 .AND. IDAY .LE. 29
```

```
     1 .AND. IDOW .EQ. 7)  GOTO 500
C-------------- General holidays for all years from 1979 to 1993
C-------------- (1)  1st weekday in Jan
C-------------- (2)  Xmas day (or 2nd weekday after if Xmas on Sunday)
C-------------- (3)  1st weekday after Xmas day
C-------------- (4)  Liberation day (the last Monday in August)
 250  IF (IMO .EQ. 1 .AND. IDAY .EQ. 1 .AND. IDOW .NE. 1)  GOTO 500
      IF (IMO .EQ. 1 .AND. IDAY .EQ. 2 .AND. IDOW .EQ. 2)  GOTO 500
      IF (IMO .EQ. 12 .AND. IDAY .EQ. 25 .AND. IDOW .NE. 1)  GOTO 500
      IF (IMO .EQ. 12 .AND. IDAY .EQ. 26 .AND. IDOW .NE. 1)  GOTO 500
      IF (IMO .EQ. 12 .AND. IDAY .EQ. 27 .AND. (IDOW .EQ. 2
     1 .OR. IDOW .EQ. 3))  GOTO 500
      IF (IMO .EQ. 8 .AND. IDAY .GE. 25 .AND. IDOW .EQ. 2)  GOTO 500
      GOTO 1000
 500  ISCDAY=8
C-------------- Store original schedule values in static arrays
      XXX90=1
      XXX91=OCC
      XXX92=LTP
      XXX93=LTI
      XXX94=EQ1
      XXX95=INF
C-------------- Override schedule values for a holiday
      EQ1=.02
      INF=1
      OCC=.05
      LTP=.1
      LTI=.1
      IF (ISCHR .LT. 7 .OR. ISCHR .GT. 18) GOTO 700
 600  GOTO 1000
 700  OCC=0
      LTP=.05
      LTI=.05
1000  CONTINUE
      END
END-FUNCTION  ..
$-----------------------------------------------------------------
$ Function to reset schedule values if changed
$-----------------------------------------------------------------
FUNCTION NAME=HOLRESET  ..
ASSIGN
      IDOW=IDOW
      IYR=IYR
      IMO=IMO
      IDAY=IDAY
      ISCHR=ISCHR
      ISCDAY=ISCDAY
      OCC=SCHEDULE-NAME(OCC-SCH)
      LTP=SCHEDULE-NAME(LGP-SCH)
      LTI=SCHEDULE-NAME(LGI-SCH)
      EQ1=SCHEDULE-NAME(EQP-SCH)
      INF=SCHEDULE-NAME(INF-SCH)
      XXX90=XXX90
      XXX91=XXX91
      XXX92=XXX92
      XXX93=XXX93
      XXX94=XXX94
      XXX95=XXX95  ..
CALCULATE  ..
C-------------- Reset schedule values if they are changed
```

```
      IF (XXX90 .EQ. 1) GOTO 10
      GOTO 20
10    OCC=XXX91
      LTP=XXX92
      LTI=XXX93
      EQ1=XXX94
      INF=XXX95
20    CONTINUE
C-------------- If leap year, up one weekday on last hour of Feb 28
1000  IF ((IYR .EQ. 1980 .OR. IYR .EQ. 1984 .OR. IYR .EQ. 1988 .OR.
     1 IYR .EQ. 1992) .AND. IMO .EQ. 2 .AND. IDAY .EQ. 28 .AND.
     2 ISCHR .EQ. 24)   GOTO 1100
      GOTO 1200
1100  IDOW = IDOW + 1
1200  CONTINUE
C-------------- Diagnostic print-out for checking
C      PRINT 1300
C1300  FORMAT(21H TEST OF RESET FUNCTION)
C      PRINT 1400, IMO,IDAY,ISCHR,IDOW,ISCDAY
C1400  FORMAT(1X,5F10.1)
      END
END-FUNCTION  ..
```

From the Building Energy Simulation User News, Vol. 15, No. 4 (Winter 1994)

Overview of SYSTEMS Schedules in DOE-2

by
René Meldem

The appropriate use of schedules is necessary for a reliable DOE-2 simulation. In some schedules specific numbers have special meanings; however, the same numbers may not have the same significance in other schedules. It's easy to become confused by schedule use if, for instance, you try to use the same schedule for fans and domestic hot water pumps. A value of -999 in the fan schedule acts as a flag value for optimum start, but in the domestic hot water schedule the same value is treated simply as a multiplier, thus producing unexpected results.

To shed some light on the proper use of schedules, we have compiled a summary of the available schedules in SYSTEMS along with their possible hourly values and corresponding effects. In the Value column of the following table, 0-1 means any value between 0 and 1, including 0 and 1; 0,1 means 0 or 1, specifying an off/on schedule; DEFAULT indicates that the consequence of not specifying the schedule is shown under Meaning ;and ANY-NUMBER means that the schedule value is unrestricted.

Command Keyword	Value	Meaning
ZONE-CONTROL		
HEAT-TEMP-SCH/ COOL-TEMP-SCH	DEFAULT >0	No zone-level heating or cooling control. Zone thermostat heating/cooling setpoint.
ZONE-AIR		
SS-VENT-SCH	DEFAULT 0,1	No sunspace venting. Specifies when a sunspace can be vented.
SS-VENT-T-SCH	ANY-NUMBER	Specifies the sunspace air temperature above which venting occurs.
SS-FLOW-SCH	0-1	Modifies the air flow between a sunspace and its adjacent rooms.
SS-FLOW-T-SCH	DEFAULT ANY-NUMBER	74F Specifies the adjacent room temperature above which the air flow from the sunspace is cut off.
ZONE-FANS		
ZONE-FAN-T-SCH	ANY-NUMBER between the heating and cooling setpoints.	For a parallel-type induction unit, gives the room temperature at which the unit blower turns on. This should normally be between the heating and cooling setpoints.
ZONE		
MIN-CFM-SCH/ MIN-FLOW-SCH	0-1	Allows an hourly variation of the minimum air flow by overriding MIN-CFM/RATIO (MIN-FLOW-RATIO).
	-999	For the hour, takes the calculated value of MIN-CFM-RATIO (MIN-FLOW-RATIO).
TROM-VENT-SCH	0,1	Specifies when natural convection can occur between a Trombe wall and its adjacent space.
SYSTEM-CONTROL		
HEATING-SCHEDULE/ COOLING-SCHEDULE	1 (DEFAULT) 0 >1	Heating/cooling available from PLANT. Heating/cooling not available from PLANT. For HEATING-SCHEDULE, the outside air temperature above which heating is not available from PLANT. For COOLING-SCHEDULE, the outside air temperature below which cooling is not available from PLANT.
HEAT-RESET-SCH/		Defines a relationship between the heating/cooling supply air

COOL-RESET-SCH		temperature and the outside air temperature when HEAT- or COOL-CONTROL = RESET.
HEAT-SET-SCH/ COOL-SET-SCH		Specifies the heating/cooling air supply temperature when HEAT- or COOL-CONTROL = SCHEDULED.
MIN-SUPPLY-SCH		Specifies the minimum cold air supply temperature when simulating a chilled water reset or other type of capacity control.
BASEBOARD-SCH		Defines a relationship between the baseboard heat output and outside air temperature when BASEBOARD-CTRL = OUTDOOR-RESET.
SYSTEM-AIR		
MIN-AIR-SCH	0-1	Specifies the minimum outside air as a ratio of the design flow rates.
	0	Outside air damper is closed (no outside air).
	-999	Takes the values specified under SYSTEM-AIR or ZONE-AIR.
VENT-TEMP-SCH	DEFAULT ANY-NUMBER	(HEAT-TEMP-SCH)+ * (THROTTLING-RANGE). Specifies the indoor air temperature below which natural ventilation or night ventilation is suppressed.
NATURAL-VENT-SCH	0	The windows remain closed.
(RESYS)	1	The windows are open only if they provide enough cooling to keep the zone temperature within or below the throttling range for cooling. Same as 1, with the additional condition that the outside air enthalpy must be below the indoor air enthalpy.
	-1	Same as 1, with the additional condition that the outside air enthalpy must be below the indoor air enthalpy.
OPEN-VENT-SCH	0-1	Specifies the probability that the window is open when VENT-TEMP-SCH and NATURAL-VENT-SCH are satisfied.
SYSTEM-FANS		
FAN-SCHEDULE	1	Fans are on.
	0	Fans are off but can be turned on if NIGHT-CYCLE-CTRL and zone temperature allow it.
	-1	Fans are off in any circumstances.
	-999	Allows an early start of the fan so that the desired zone temperatures are achieved during the first hour following the optimum start period.
NIGHT-VENT-SCH	0,1	Specifies when fans are allowed to turn on at night when NIGHT-VENT-CTRL = WHEN-SCHEDULED or SCHEDULED+DEMAND.
SYSTEM-FLUID		
INDUC-MODE-SCH	>0	The zone coils of a two-pipe induction unit (TPIU) provide cooling only.
	<0	The zone coils of a two-pipe induction unit (TPIU) provide heating only.
SYSTEM		
EVAP-PCC-SCH	0	Evaporative precooler for the air cooled condenser of a DX unit is not operating.
	1	Evaporative precooler is operating.
	>1	Evaporative precooler is operating only if the outside temperature is less than the value in the schedule.
	<0	Evaporative precooler is operating only if the outside temperature is greater than the absolute value of the schedule value.
PLANT-ASSIGNMENT		
BOILER-MAX-SCH	DEFAULT =	BOILER-MAX-RATIO; boiler's maximum operating capacity

		as a fraction of design output (given by boiler size).
BOILER-SCH	DEFAULT 0 1 >1	CIRC-PUMP-SCH. Boiler is off. Boiler is on. Outside air temperature below which heating is available. Note: should be compatible with CIRC-PUMP-SCH when applicable.
BOILER-SET-SCH	DEFAULT	BOILER-SET-POINT allows adjustment of the boiler's set point.
DHW-INLET-T-SCH	DEFAULT ANY-NUMBER	The domestic hot water inlet temperature is set to the ground temperature from the weather file. Specifies the domestic hot water inlet temperature.
DHW-PUMP-SCH	0,(DEFAULT) 1	Domestic hot water pump is off. Domestic hot water pump is on.
DHW-SCH	0-1	Specifies the building-level hot water use; multiplies DHW-GAL/MIN.
INT-FUEL-SCH/ EXT-FUEL-SCH	0-1	Specifies the building-level interior/exterior fuel use as af unction of time. The number entered is a fraction that multiplies INT- or EXT-FUEL-BTU/HR (INT- or EXT-FUEL-POWER).
INT-ELEC-SCH	0-1	Specifies, as a fraction of INT-ELEC-KW, the building-level electricity that does not contribute to space loads (elevators, etc.).
EXT-ELEC-SCH	0-1	Same as INT-ELEC-KW but for exterior electricity consumption(exterior lighting, etc.).
EXT-LIGHT-SCH	0-1	Schedule for exterior lighting; modifies EXT-LIGHT-KW.
PROCESS-HW-SCH/ PROCESS-CHW-SCH	0-1	Specifies the building process hot/chilled water use. Multiplies PROCESS-HW-BTU/HR (PROCESS-HW-POWER) or PROCESS-CHW-BTU/HR (PROCESS-CHW-POWER).
CIRC-PUMP-SCH	DEFAULT 0,1	Always on. Allows control of the HP system circulation pump.
TWR-SCH	DEFAULT 0 1 >1	CIRC-PUMP-SCH. Tower is not available. Tower is available. Outside air temperature above which the tower is available. Note: Should be compatible with CIRC-PUMP-SCH.
TWR-SETPT-SCH	DEFAULT OTHER	TWR-SETPT-T. Specifies the tower setpoint; overrides the value given by TWR-SETPT-T.

<u>From the Building Energy Simulation User News, Vol. 15, No. 3 (Fall 1994)</u>

The Power Of Hourly Reports

by

René Meldem

Question:

Why does this Dual Duct system consume so much more cooling energy than a Variable Volume system? The electricity bill seems much too high; and the pumping energy is much too low. There must be a bug in the program!

Answer:

You may often be puzzled if you look critically at the results of aDOE-2 simulation. The numbers may not make sense; your intuition maybe challenged. So what should you do to understand how DOE-2 is interpreting your input? How can you be sure that the system you're modeling acts the way you want it to? Where can you look if you're confused by the monthly and annual numbers in the summary reports? Look at the hourly reports!

Appendix A of the Supplement (2.1E) is an extensive list of the hundreds of hourly variables you can review, ranging from loads, to temperatures, flows, and energy use. Although checking the hourly reports requires time and patience, your efforts will be rewarded as you gain a better understanding of how your building and systems are performing. You will also be able to see what keyword default values are being used that you may have overlooked, keywords that could have a big effect on your results. Only by checking hourly values can you be assured of a reliable, high quality simulation.

There are many examples where checking hourly reports have helped users to correct their input. We will use the case of a problem that was recently reported to us to illustrate the use of hourly reports. A user wanted to compare the performance of a VAV (Variable Air Volume) system with a MZS (Multi-Zone Fan System) in an office building. He was surprised that the heating energy for the MZS system was much higher than that for the VAV system; he expected approximately the same heating energy for both systems. So he checked the hourly reports and found that at night, to hold the setback temperature, the MZS system had maximum outside air flow, while the VAV system was at minimum outside air. This problem was easily fixed by specifying zero outside air for the MZS system when the building was unoccupied.

In conclusion, please take the time to check hourly reports even if you think everything looks okay. This will improve your understanding of how your building performs and will assure a high quality simulation.

From the Building Energy Simulation User News, Vol. 15, No. 2 (Summer 1994)

Using DOE-2 Input Functions to Determine Building Load with Outside Air

by
Ellen Franconi

The DOE-2 system type SUM determines building load based on actual zone temperatures. The load determined with SUM is more accurate than the load determined in LOADS because the LOADS value is based on a constant space temperature (default 70F). However, since system type SUM is not an actual system, it does not model outdoor air ventilation; therefore, it does not include the building's fresh air requirements as part of the building load.

Recently, I worked on two projects that required the calculation of building load including outdoor air. After using a kludgey -but-effective method to get the desired results, by coupling outdoor air requirements with the infiltration rate for the first project, it seemed worthwhile to write a DOE-2 function to determine the load as part of the SUM calculation for the second project. The function is slightly different for DOE versions 2.1D and 2.1E. Both versions are presented.

The function can easily be incorporated into a DOE-2 run by adding the line

```
SUBR FUNCTIONS SUM 2Z = *OAIR*  ..
```

after INPUT SYSTEMS and before the SYSTEM command. The function uses the input keywords for occupancy (N-O-P) and outdoor air requirements per person(OA-CFM/PER) to include the outdoor air load in the building load calculation. Therefore, these keywords must be specified in the run. The function will calculate the building load for all hours. It includes the outdoor air load in the load calculation for hours in which the system fan is on. Although the default for fans is ALWAYSON with SUM, a fan schedule should be specified for SUM when the function is used. Use the same schedule that you would use when modeling the actual system.

In addition, it is best to oversize SUM by specifying SIZING RATIO = 3. Some detective work by Joe Huang (of the Energy Analysis Program at Lawrence Berkeley Laboratory) uncovered that SUM has the tendency to clip loads if the building load is modified in SYSTEMS. This is because SUM only uses the peak loads from LOADS for sizing. Thus, a function like OAIR that adds outside air in SYSTEMS can result in SUM being undersized. Likewise, SUM can be undersized if the building has an unconditioned space, like a basement, since loads from unconditioned spaces are analyzed in SYSTEMS. For the commercial building prototypes developed at LBL, we found using a sizing ratio of of at least 2 took care of the problem. We use a value of 3 in our runs, but it doesn't matter if you use a sizing ratio of 3 or 10 or even 100 with SUM. Its efficiency is 100% under full or part load.

A sample input for SUM is given below.

```
SYS1     SYSTEM
         SYSTEM TYPE      SUM
SIZING RATIO     3
         FAN SCHEDULE     FAN SCHED
         ZONE NAMES       (COR I1,COR 1,
                           PER 1,PER 2,PER 3,PER 4,
                           PER I1,PER I2,PER I3,PER I4,BASE 1)
          ..
```

Function for SUM with outdoor air load for DOE-2.1D

```
$ Add this line after <INPUT SYSTEMS   .. > command

SUBR FUNCTIONS SUM 2Z = *OAIR*  ..

$ Insert function after system END and before COMPUTE

FUNCTION NAME = OAIR  ..
 $
 $    This function adds the outside air load to the loads determined
 $    using system SUM based on the maximum number of occupants and
 $    the outdoor air cfm/person.
 $
 $    The FAN SCHED, which is usually set to ALWAYSON with SUM, needs
 $    to be set to the schedule the fan would follow with a system.
 $    The building load is summed for all hours and the load from
 $    outside air is determined for the hours the system fan is on.
 $
ASSIGN
      MON=IMO DAY=IDAY HR=IHR
INFCFM =CFMINF
      ATMPRES=PATM
      NZ=NZ NSZ=NSZ
      NOP=PEOPLE
      OACFMPP=OA CFM/PER
      ZP2=ZP2 FON=FON
      TOUT=DBT  ZONELD=QS  ..
CALCULATE   ..
      IF(NZ.EQ.1 .AND. FON.EQ.0) IFLAG=0
      IF(NZ.EQ.1 .AND. FON.EQ.1) IFLAG=1
      FON=1.
      TIN=ACCESS(ZP2+124)
      IF(IFLAG.EQ.0) GO TO 5
      LDSRANK = TIN + 460
      OACFM = NOP*OACFMPP
      ADDLD= 14.4*(ATMPRES/(.754*LDSRANK))*(TOUT TIN)*OACFM
      ZONELD=ZONELD+ADDLD
      INFCFM=INFCFM+OACFM
 5    CONTINUE
      END
END FUNCTION  ..
```

Function for SUM with outdoor air load for DOE2.1E

```
          FUNCTION NAME = OAIR  ..
 $
 $    This function adds the outside air load to the loads determined
 $    using system SUM based on the maximum number of occupants and
 $    the outdoor air cfm/person.
 $
 $    The FAN SCHED, which is normally set to ALWAYSON with SUM, needs
 $    to be set to the schedule the fan would follow with a system.
 $    The building load is summed for all hours and the load from
 $    outside air is determined for the hours the system fan is on.
 $
ASSIGN
      MON=IMO DAY=IDAY HR=IHR
      INFCFM =CFMINF
      ATMPRES=PATM
      NZ=NZ NSZ=NSZ
      NOP=PEOPLE
      OACFMPP=OA CFM/PER
      TIN=TLOADS FON=FON
      TOUT=DBT  ZONELD=QS  ..
CALCULATE   ..
      IF(NZ.EQ.1 .AND. FON.EQ.0) IFLAG=0
      IF(NZ.EQ.1 .AND. FON.EQ.1) IFLAG=1
FON=1.
      IF(IFLAG.EQ.0) GO TO 5
      LDSRANK = TIN + 460
      OACFM = NOP*OACFMPP
      ADDLD= 14.4*(ATMPRES/(.754*LDSRANK))*(TOUT TIN)*OACFM
      ZONELD=ZONELD+ADDLD
      INFCFM=INFCFM+OACFM
 5    CONTINUE
      END
END FUNCTION  ..
```

From the Building Energy Simulation User News, Vol. 15, No. 2 (Summer 1994)

Weather Files vs DESIGN-DAY

by
René Meldem

Question:

I used DOE-2 to size the central cooling coil of a VAVS system for a community building with occupancy from 3:00 pm through midnight. Instead of DESIGN-DAYs, I used a TRY weather file to size the system. Then I ran DOE-2 using two different weather data for very similar climates and obtained very different values for COOLING-CAPACITY (SV-A). What happened?

Answer:

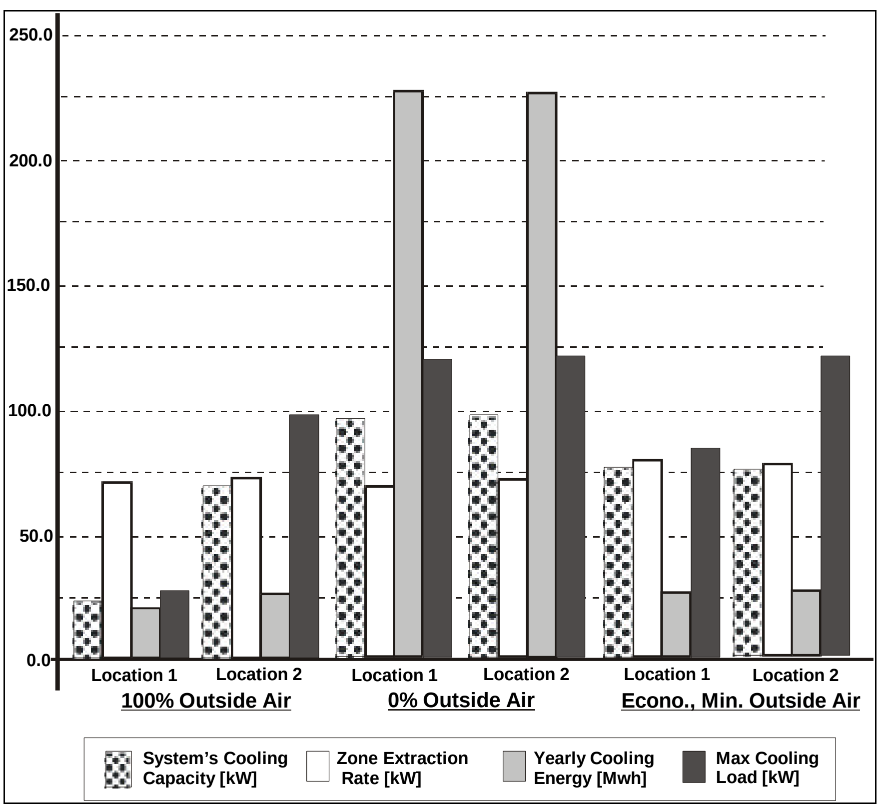
This is a somewhat delicate problem. The VAV system you designed has the following characteristics.

The system uses 100% outside air. The outside air temperature and humidity are different for the peak hour for different locations:

23° C DBT, 17° C WBT for location 2;
18° C DBT, 13° C WBT for location 1.

Therefore, for the same airflow, the size of the cooling coil will be as different as the enthalpy difference between the outside air and the cooling setpoint at the peak. The peak load from LOADS is mainly occupancy-dependent, since the room is occupied at night when the exterior conduction and solar loads are no longer significant. If you want to size your system using a weather file rather than DESIGN-DAYs, I recommend that you set the minimum outside air to be proportional to the number of people (whether you use an economizer or not). Also, you should specify the same schedule for every day of the week in the sizing process. Once the sizing has been done, you can activate the usual activity schedules and perform further energy analysis. If you follow these recommendations, the discrepancy in the size of the cooling coil will disappear, as shown in the figure below.

In general, if you want to size a system or plant using a weather file, you should be careful about the operation mode of the mechanical devices, as well as the influence of the schedules on the LOADS calculation.



From the Building Energy Simulation User News, Vol. 15, No. 1 (Spring 1994)

Using DESIGN DAY

by

René Meldem

Question:

Why is there no solar gain on my reports? I'm trying to size a system using a typical DESIGN DAY with as many RUN PERIODs asDESIGN DAYs. What do I have to do to get solar gain?

Answer:

If a run is made using DESIGN DAY only, and you do not specify a RUN PERIOD for the weather file, nor do you specify the building latitude, longitude, or time zone under BUILDING LOCATION, then the solar gain will be zero! This is because the coordinates of the building are mandatory in order to calculate sun position and, thus, solar gain. If a RUN PERIOD is specified using a weather file, then DOE-2 looks into the weather file for default values of latitude, longitude, and time zone and plugs them into the solar radiation calculation procedure.